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ASD INTERIM REPORT 7-878 (II)
March 1962

SANDWICH ROCKET MOTOR CASE PROGRAM

R. W. Spencer
E. H. Baker
D. H. Wykes

North American Aviation, Inc.
Space and Information Systems Division

SID 62-363

Contract AF 33(600)-43031
ASD Project 7-878

Interim Technical Engineering Report
29 September 1961 - 23 March 1962

A description is given of the fabrication studies and tests to determine the material allowables for, together with a description of, subscale and full-scale filament-wound sandwich rocket motor cases.

Manufacturing Technology Laboratory
Aeronautical Systems Division
United States Air Force
Wright-Patterson Air Force Base, Ohio

ABSTRACT - SUMMARY
Interim Technical Progress Report

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A description is given of the fabrication studies and tests to determine the material allowables for, together with a description of, subscale and full-scale filament-wound sandwich rocket motor cases.

This report summarizes the edgewise compression and small-scale sandwich-wall cylinder tests that were initiated in phase I of the subject contract to determine design values for sizing the subscale and full-scale sandwich rocket motor cases. The fabrication process used to build the sandwich-wall cylinders and subscale cases is described in detail, together with the associated mandrel-tooling development studies.

The test results of the subscale motor cases are discussed and analyzed in detail. A subscale case was built which exceeded the ultimate design pressure by 10 percent.

A detailed stress analysis for the full-scale rocket motor cases is presented, together with design drawings of the motor case, nozzle, and internal insulation.

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FOREWORD

This Interim Technical Progress Report covers the work performed under Contract AF 33(600)-43031 from 29 September 1961 to 23 March 1962. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This is the second of four interim reports to be issued under the above contract. The contract is a 3-phase study of the feasibility and manufacturability of a sandwich rocket motor case culminating in the actual fabrication and static firing of the sandwich rocket motor case.

Approved by: Cornelius Boogaard
Project Manager,

Approved by: Dr. L. A. Harris
Director, Structural Sciences

Approved by: ____________________
Dr. G. C. Clementson
Director, Aerospace Technology

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APPENDIXES

ILLUSTRATIONS

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ERRATA

Subsequent to printing of AMC Interim Report 7-878 (I), several errors were discovered. These errata are herein noted.

"Figure 11. Axial Load at Maximum q for ICBM"
Should Read: "Figure 12. Shear and Bending Moment at End of First Stage Boost for ICBM."

"Figure 12. Shear and Bending Moment at End of - - - - -"
Should Read: "Figure 13. Axial Load at End of - - - - -"

"Figure 13. Axial Load at End of First Stage Boost for ICBM"
Should Read: "Figure 11. Axial Load at Maximum q for ICBM."

Figure 14. In Field of Figure Note 3, "$\dddot{\theta}$ - 1.49 RAD/SEC"
Should Read: "$\ddot{\theta}$ = -1.49 RAD/SEC^2"

Figure 28. Same as Figure 14.

Page 74. Printing error continuity from page 73 to 75

Page 77. Under "Subscale Design," First Sentence should read; - - - "160,000 pounds per square inch."

Figure 53. "Angle α_σ" should read "Angle α"

Page 82. Last sentence should read:
"α is a function of the shear rigidity - - -"

Figure 28. Printed erroneously as Figure 14.

I. COMPLETION OF PHASE I STUDIES

INTRODUCTION

This is the second interim technical engineering report for Contract AF 33(600)-43031. The principal objective of this contract is to evaluate the feasibility of sandwich-type construction for upper stage solid rocket motor cases. This investigation is being conducted by the Space and Information Systems Division (S&ID) of North American Aviation, Inc., with the fabrication support of the Corporation's Rocketdyne Division. The program is sponsored by the Aeronautical Systems Division of Wright-Patterson Air Force Base (WPAFB). The program is divided into the following 3 phases: (1) feasibility studies of sandwich motor cases, (2) construction and static tests of subscale cases to verify analytical methods, and (3) fabrication and test of full-scale cases. Phases I and II have been completed. This report primarily will discuss the results of phase II of this program.

SUMMARY OF PHASE I TESTING

Four series of tests were conducted during phase I to determine design allowables for filament-wound fiberglass in compression. These allowables were required for the design of the sandwich rocket motor case to be built in phase II of this study program. The following tests were conducted:

1. Block shear tests - to evaluate core-to-facing bond.

2. Thick-walled cylindrical compression tests - to determine compression allowables for filament-wound fiberglass materials.

3. Edgewise compression tests of flat laminate fiberglass specimens - to determine the effects of temperature on the resin system to be used for the motor cases.

4. Thin-facing, cylindrical sandwich specimens - to determine compression design values for thin, filament-wound sandwich facing sheets.

The first two series of tests were reported in the AMC Interim Report 7-878(I). The remaining tests will be described in this report.

EDGEWISE COMPRESSION SPECIMENS

Flat panels were laminated, using No. 143 fiberglass cloth impregnated with U.S. Polymeric E787 resin. The 143-plys were oriented, as shown in Figure 1, to achieve a fiber orientation, bulk factor, and the longitudinal-to-transverse filament properties equal to that which would be obtained in the facings of the cylindrical portion of the rocket motor cases. The resin content of the "pre-preg" was maintained at 30 percent ± 3 percent, and a laminating pressure of approximately 50 psi was used to achieve a laminated resin content equal to that of a filament-wound construction cure cycle. The detailed cure was accomplished in the following manner:

To simulate the pressure distribution of a filament-wound facing on a honeycomb core, the panels were laid up on a piece of 3/16-inch x 0.004-inch aluminum honeycomb core with a strip of No. 181 glass strip-cloth as a separator. This fabrication technique produced cure conditions representative of the external facings and was slightly conservative for the inner facings. The laminates were then cured in a press at 50 psig for one hour at 250° F plus 2 hours at 350° F, which was the proposed cure for the sandwich cases. Following the cure, the core material and glass cloth were stripped from the panel.

Subsequent contacts with U.S. Polymeric engineers revealed that the cure cycle used for these test specimens was not optimum for U.S. Polymeric E787 resin when that resin system is to be used at elevated temperatures. The cure cycle they recommended cannot be readily achieved with the use of heavy metal or plaster mandrels. Because of the large heat-sink, the time required to reach cure temperature is increased markedly over the otpimum suggested. In the opinion of the suppliers, a slow heat-up cycle causes increased resin migration and may even cause local depleted resin content in the inner laminates. The scope of the contract precluded the use of light, breakaway production-type tooling. The cure cycle used is, therefore, considered to be most representative of that which would be achieved during fabrication of the rocket engine cases.

Specimens similar to the compression specimens were simultaneously fabricated, with thermocouples imbedded, to serve as dummy specimens to determine a thermal exposure cycle equivalent to that which would be experienced in flight.

The compression test specimens were machined from the fabricated panels to the configuration shown in Figure 1. The compression specimens were tested in accordance with Military Specification LP 406 in the compressive fixture shown in Figure 2. A total of 5 specimens were tested at each of the following temperatures: room temperature, 200° F, 300° F,

and 500° F. The thermal cycles to which the specimens were exposed are shown in Figure 3.

The detailed data obtained from the test is recorded in Table 1 and the average data is presented in Figure 4. The test results, particularly at elevated temperatures, were quite illuminating and disappointing since we had been assured, based on conventional flexural and tensile specimen tests, that the E787 resin system would achieve elevated temperature properties considerably higher than those realized.

SANDWICH-WALL CYLINDERS

It was believed that the edgewise compression properties of the thin-walled facings of the sandwich rocket engine cases might prove to be considerably different from those obtained with thick-walled cylinders. Small sandwich cylinders were fabricated with facings representative of the filament-wound construction and gages identical to those proposed for subscale and full-scale motor cases. Sandwich-wall specimens were tested because the core of the sandwich stabilizes the facing and prevents stabilization failures. Therefore, the ultimate compressive stress of the facing material can be obtained.

The sandwich cylinders were fabricated in the general configuration shown in Figure 5. The facing gages were approximately 0.040-inch thick The core height was 0.500 inches and Narmco Multiwave core was used to permit ease of fabrication without specialized tooling. The adhesive system for bonding the facing to core was Bloomingdale HT 432, which is a light-gage HT 424 tape used at NAA. The core splices and core-to-end reinforcement bond was accomplished with the Bondmaster M 611 adhesive system. The general procedure used to fabricate all 6 specimens is described in Section IV of this report. Seven specimens were fabricated with numerous deviations occasioned by manufacturing variables. During fabrication of the test specimens, some delamination occurred between the core and the inner facing of the cylinders. (A typical example is illustrated in Figure 6.) This occurred at times in the initial cure, but more often at the second stage cure when the end doublers were being bonded to the inner facings at 180° F. These variables are believed to have had marked effect on the resultant load-carrying capability of the cylinders. The deviations are therefore being discussed in conjunction with the individual cylinder test results. (The collective test data are recorded in Section IV of this report.)

Specimens 1 and 2 were fabricated in a manner commensurate with the basic procedure (refer to Section IV). The inner doublers were bonded with an epoxy adhesive using a fast-acting, room temperature catalyst which proved somewhat difficult to use. There was evidence of delamination at the machined ends of the cylinders. The ends were cast into metal retaining plates with an epoxy tooling resin. The facing failure was as anticipated;

however, there was some evidence of delamination between the facing and core at the failure lines. Sections were cut from the cylinder to determine the facing gages and the resin contents. It was noted that some voids existed between the core and facing; therefore, a change was instituted to substitute 0.010-gage HT 424 adhesive for the 0.005-gage HT 432 material on subsequent specimens.

Typical test instrumentation for the small sandwich cylinders tested at room temperature is depicted in Figure 7. Extensometers were applied to diametrically opposite surfaces of the cylinder with 6-inch gage lengths. Axial strain gages were installed on the first specimen to determine uniformity of loading, approximate compression modulus of the composite structure, and to ascertain any nonuniformity of failure. A simple band linkage was applied approximately at midgirth to determine the approximate Poisson's ratio of this construction. The latter instrumentation proved inadequate as a result of excessive friction in the linkage. The data were not considered important enough to refine the instrumentation, and the instrumentation was abandoned on the latter tests. The load was applied in the normal manner but held at 10,000-pound increments to permit strain gage readings. The load-strain and load-deflection data are recorded in the tables and illustrations within the detailed test report in Appendix B. The failure load for the first cylinder was 55,000 pounds, and for the second cylinder 48,250 pounds; the calculated stresses were 23,700 and 21,700 psi, respectively. The facing sheet material of both specimens failed in compression in the center section of the cylinder. Cylinder 1 failed in both faces and cylinder 2 in the outer face only. Figure 8 is typical of both specimen failures.

A review of the fabrication procedures discussed in Section IV will reveal that several simultaneous fabrication changes were instituted on specimen 3. Two were important because they influenced the structural properties of the sandwich cylinder. First, the face-to-core adhesive was changed, as discussed above; second, the adhesive catalyst and cure for secondary bonding of the end doublers was changed to one requiring an elevated temperature cure of 2 hours at 180° F. The fabrication proceeded satisfactorily through the first cure, and no facing delaminations were apparent. The new adhesive system for attachment of the doublers was instituted with the confidence that the laminate resin system was adequate for the cure temperature specified. However, when the specimen was removed from the oven after curing the laminate bond, under vacuum pressure, delaminations were apparent on the inner facing. Figure 6 shows a typical area of delamination. This specimen was sectioned as shown in Figure 8 and examined under a binocular scope to ascertain the cause. A close examination of the adhesive bond line indicated a completely satisfactory bond of the adhesive to the core, but apparent lack of adhesion to some areas of the facing, with delamination taking place in the circumferential winding.

It was propounded that residual stresses in the inner windings might be causing the delaminations when the resin was degraded slightly at 180° F. Accordingly, the 2-inch center ring section was placed in the oven at 300° F for 10 minutes, but no additional delamination occurred. The narrow end was segmented as shown, and upon measuring—after removing the segment—the diameter had decreased approximately 3/32 inches. Additional closure was prevented by the thick reinforcement at the end of the cylinder. While this study was being conducted, the fabrication of specimen 4 was completed in a similar manner to specimen 3. However, the part delaminated in a similar manner to specimen 3 after the secondary bonding operation. Specimen 4 was instrumented to obtain deflection readings only, thus permitting more uniform rate of loading until failure. With this type of loading, the specimen reached a load of 46,250 pounds, which is approximately that attained by specimen 3. The facing stress was 21,200 psi at failure.

Specimens 5 and 6 were fabricated with 0.010-inch gage adhesive throughout. Particular care was used to maintain the 0.040-inch inner wall thickness and to control each fabrication step. The delaminations appeared but in much less pronounced patterns. Deflection gages were applied, however, and the load was applied to specimen 5 in 10,000 pound increments until failure. The failing load for specimen 5 was 49,500 pounds, which produced a facing stress of approximately 23,400 psi. A typical failure occurred with local delamination at the failure area.

Specimen 6 was not instrumented in any manner, and the load was applied uniformly until failure. The failure occurred at 58,250 pounds, developing a facing stress of approximately 26,400 psi at failure.

It was decided to fabricate and test one more specimen incorporating a higher resin content in the inner circumferential windings immediately adjacent to the adhesive bond line. No delamination occurred in this specimen during the secondary bonding operation. It was decided to test this extra specimen at an elevated temperature to secure some limited design data and guidance for the subscale case design. Vertical deflection gages were installed, and a modification of a test oven was effected to soak the specimen at temperature. Because of excessive heat losses from the modified oven, it proved difficult to stabilize the heated specimen without considerable soak time. It was intended to heat the specimen to 225° to 250° F for the test. The soak cycle, however, was 1.5 hours at 160° F, plus 180° F for 1 hour, plus 200° F for 1 hour. The oven control was again adjusted upward and the test was conducted when the specimen reached 210° F. Load deflection readings were taken at intervals of 5000 pounds. Failure occurred at 25,000 pounds, which resulted in a facing stress of approximately 8500 psi. The failure pattern was normal and occurred simultaneously in several places. Figure B-2 shows the failed specimen. Numerous delaminations also occurred at the inner facing.

Table B-2 summarizes the compressive stress and modulus achieved by each of the test specimens discussed above.

STRUCTURAL WEIGHT COMPARISON

The third stage of the escape mission described in AMC Interim Report 7-878 (I) was selected for a weight trade-off study between monocoque and sandwich motor cases. (Refer to AMC 7-878 (I) for the loads and temperatures.) The cylindrical portion of the third stage motor case theoretically was designed for each of 4 different materials and 2 types of construction: sandwich and monocoque. The materials considered were filament-wound fiberglass, titanium, beryllium, and steel. The material properties used in the design are presented in Table 10 of AMC Interim Report 7-879 (I).

Cork insulation 0.03-inch thick was used on the filament-wound sandwich motor case and 0.04-inch-thick cork was used on the filament-wound monocoque case. The weight of cork left on the case after ablation was used in the weight computation.

The stabilizing effect of the propellant was neglected in the stability analysis. The weight per unit area of the cylindrical portion of a motor case, for various materials and types of construction, is listed in Table 2. It is apparent that the filament-wound sandwich is the lightest type of construction except for beryllium monocoque. However, beryllium is ruled out because of severe problems associated with fabrication, and the resulting high costs.

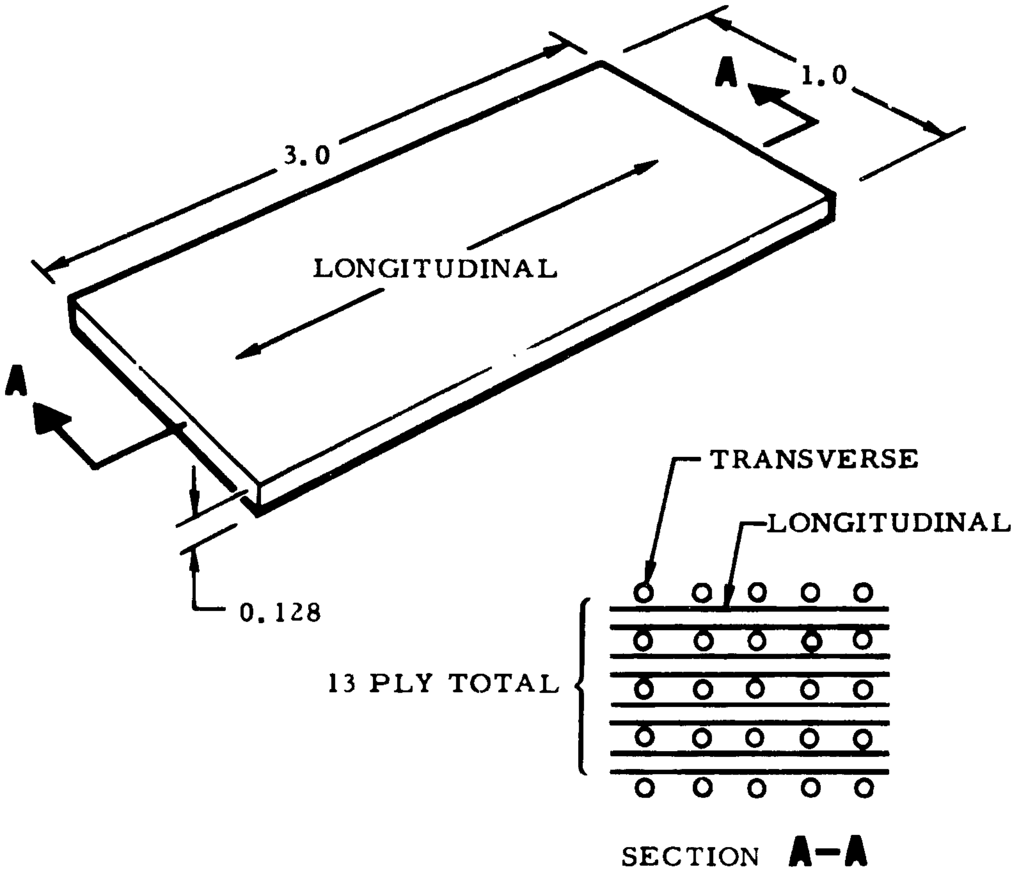


Figure 1. Edgewise Compression Specimens

Table 1. Edgewise Compressive Properties of 143 Glass Fabric/E787 Epoxy Resin Laminate

Room Temp			200° F			300° F			500° F		
No.	Ultimate Stress (psi)	Modulus 10^6 (psi)	No.	Ultimate Stress (psi)	Modulus 10^6 (psi)	No.	Ultimate Stress (psi)	Modulus 10^6 (psi)	No.	Ultimate Stress (psi)	Modulus 10^6 (psi)
1	65,500	4.48	6	32,600	*	11	7600	3.59	16	5400	3.70
2	65,500	4.54	7	34,200	*	12	8000	3.62	17	5900	3.71
3	64,900	4.55	8	37,600	*	13	8000	3.82	18	6000	4.05
4	69,500	4.59	9	35,200	3.76	14	7700	3.50	19	5800	*
5	66,800	4.61	10	30,000	3.76	15	9200	3.60	20	6800	4.06
Avg	66,400	4.55	Avg	33,900	3.76	Avg	8100	3.63	Avg	6000	3.88

*Specimens not loaded with extensometer in proper alignment

Table 2. Weight Comparison

Type of Construction	Weight per Unit Area (lb/ft^2)
Beryllium monocoque	1.14
Filament-wound Fiberglass Sandwich with Cork Insulation	1.17
Titanium Sandwich	1.48
Steel Sandwich	1.88
Filament-wound Fiberglass Monocoque with Cork Insulation	1.89
Titanium monocoque	2.16
Steel monocoque	2.60

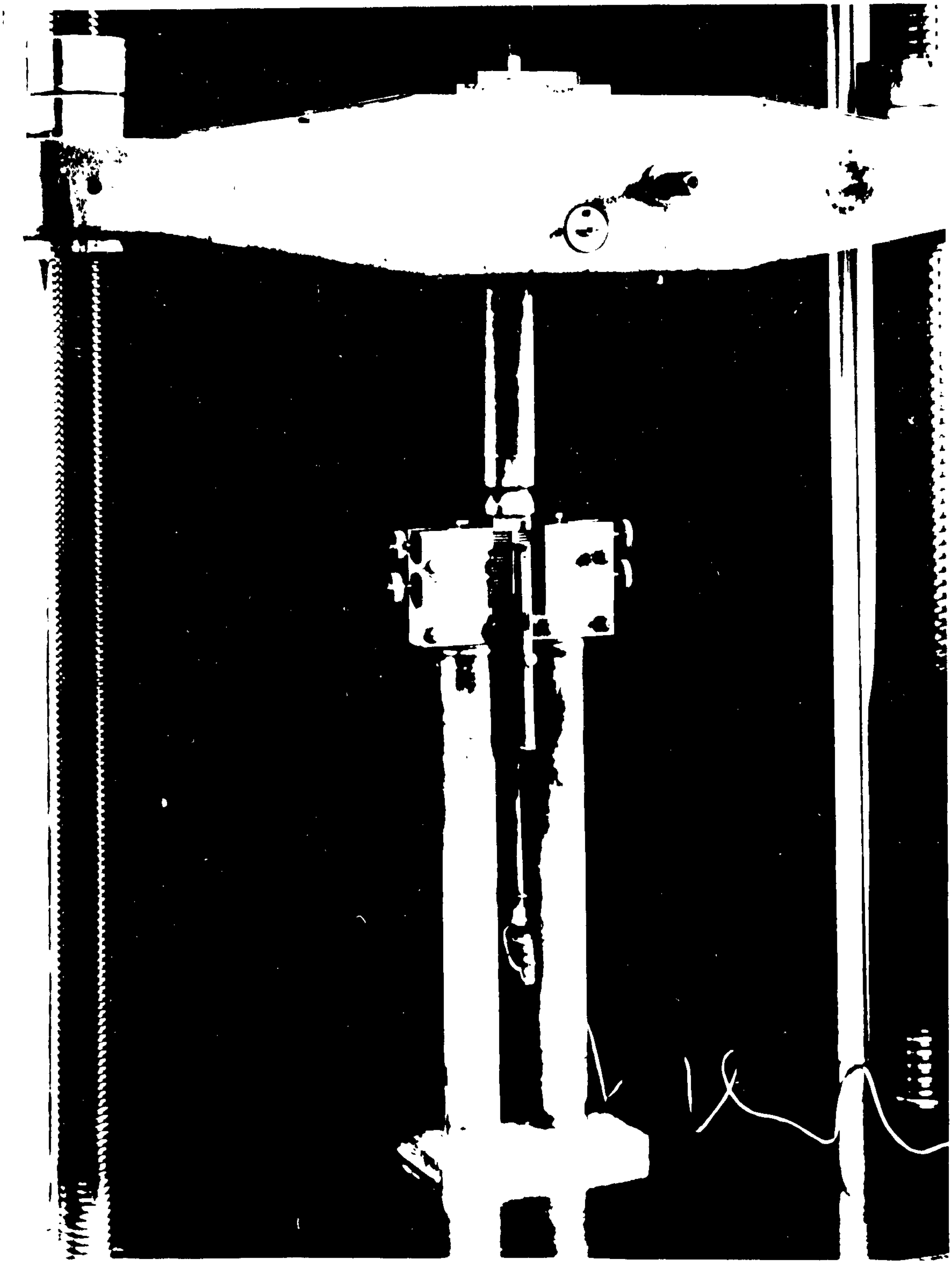


Figure 2. Typical Edgewise Compression Test Fixture

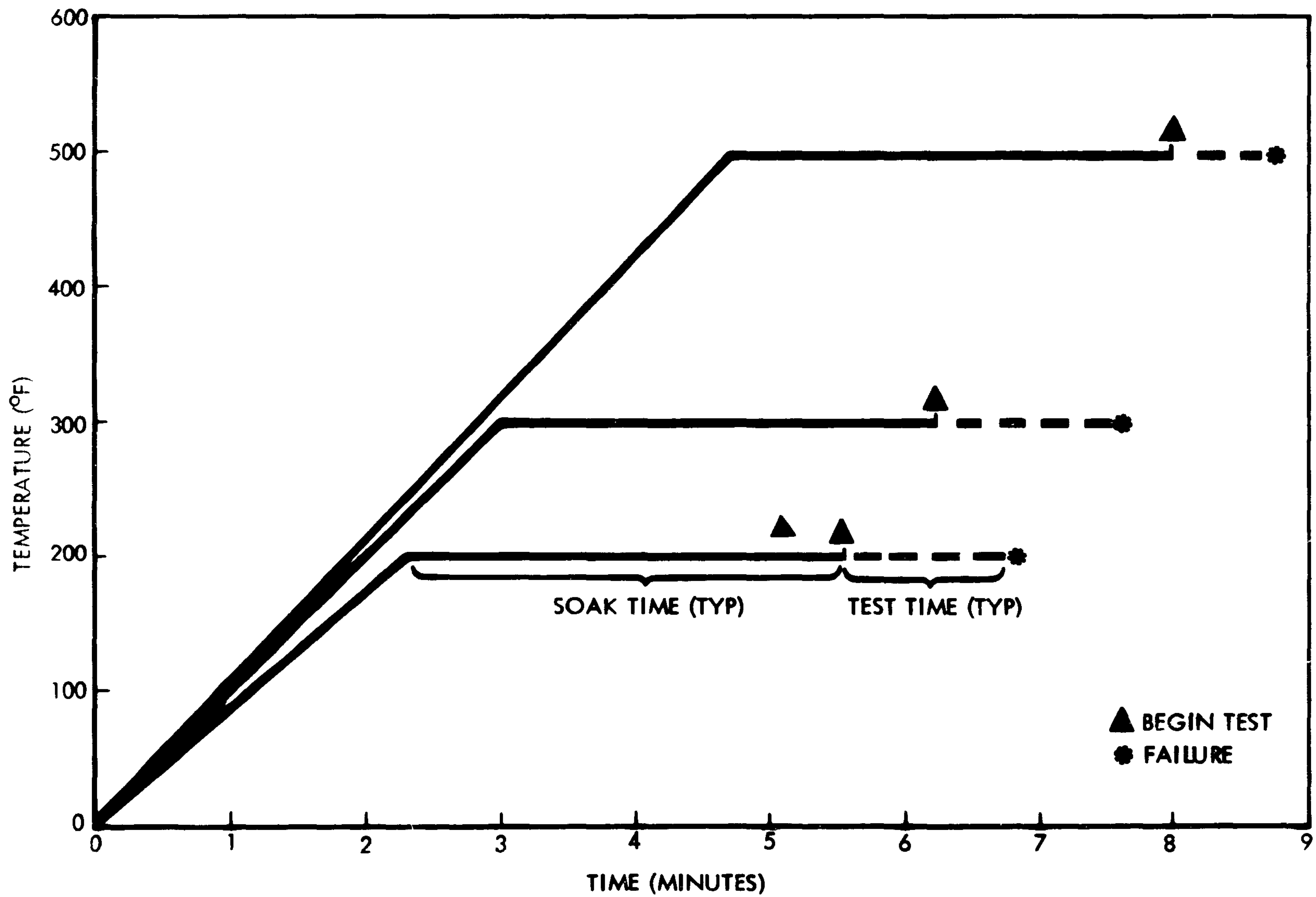


Figure 3. Thermal Exposure Cycle

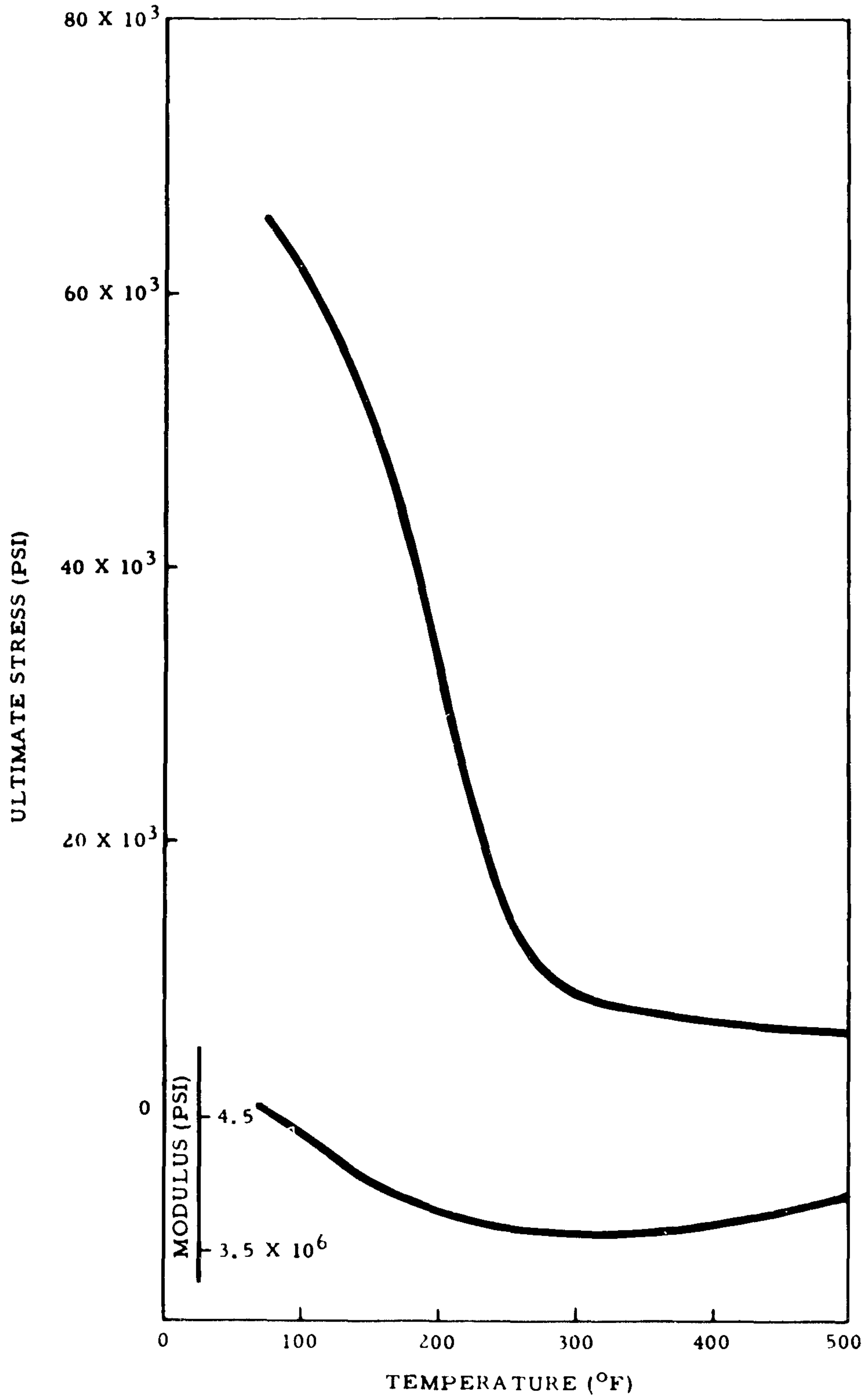


Figure 4 Edgewise Compression Test Results

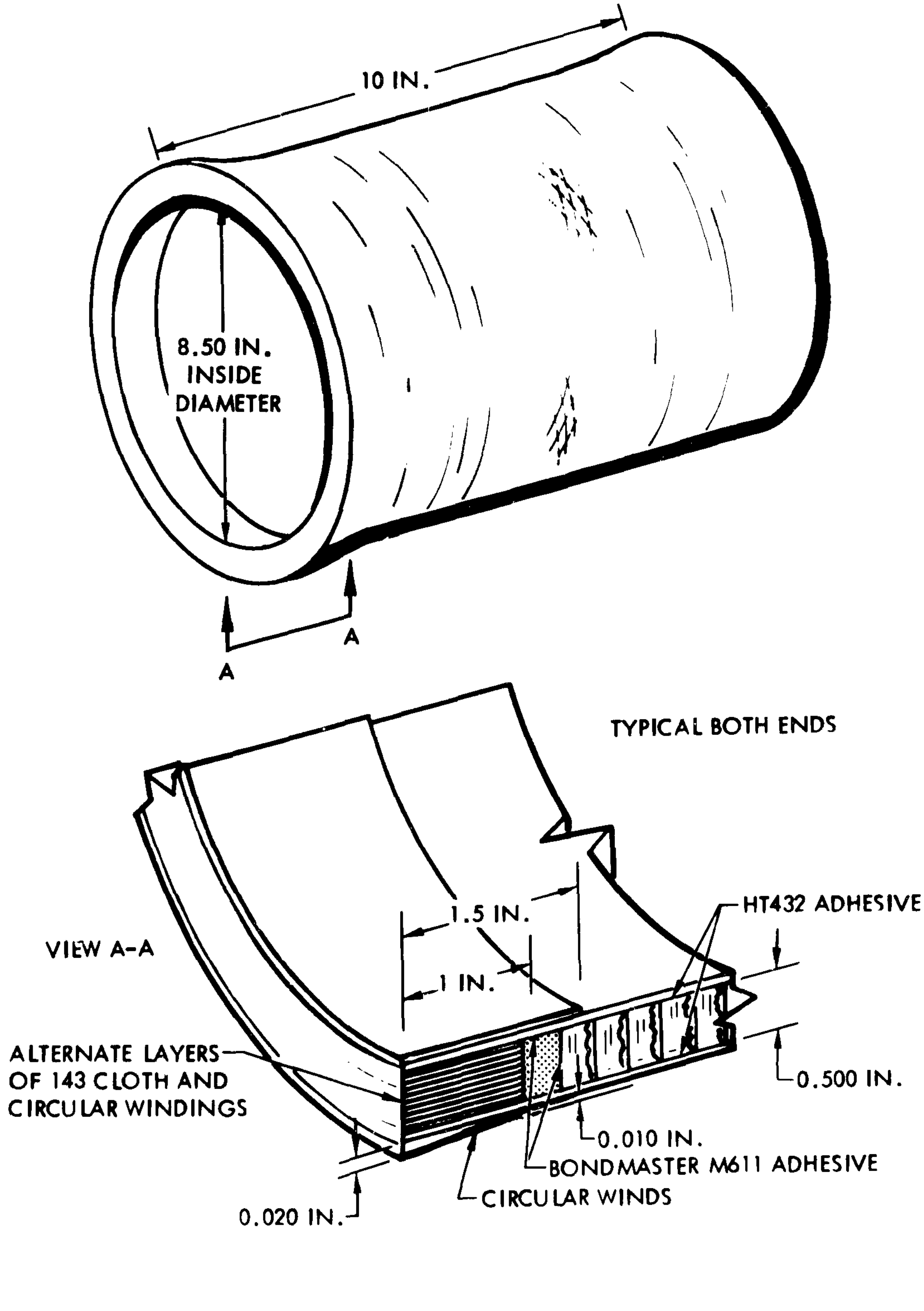


Figure 5. Sectional Diagram of Small-Scale Sandwich-Wall Cylinder

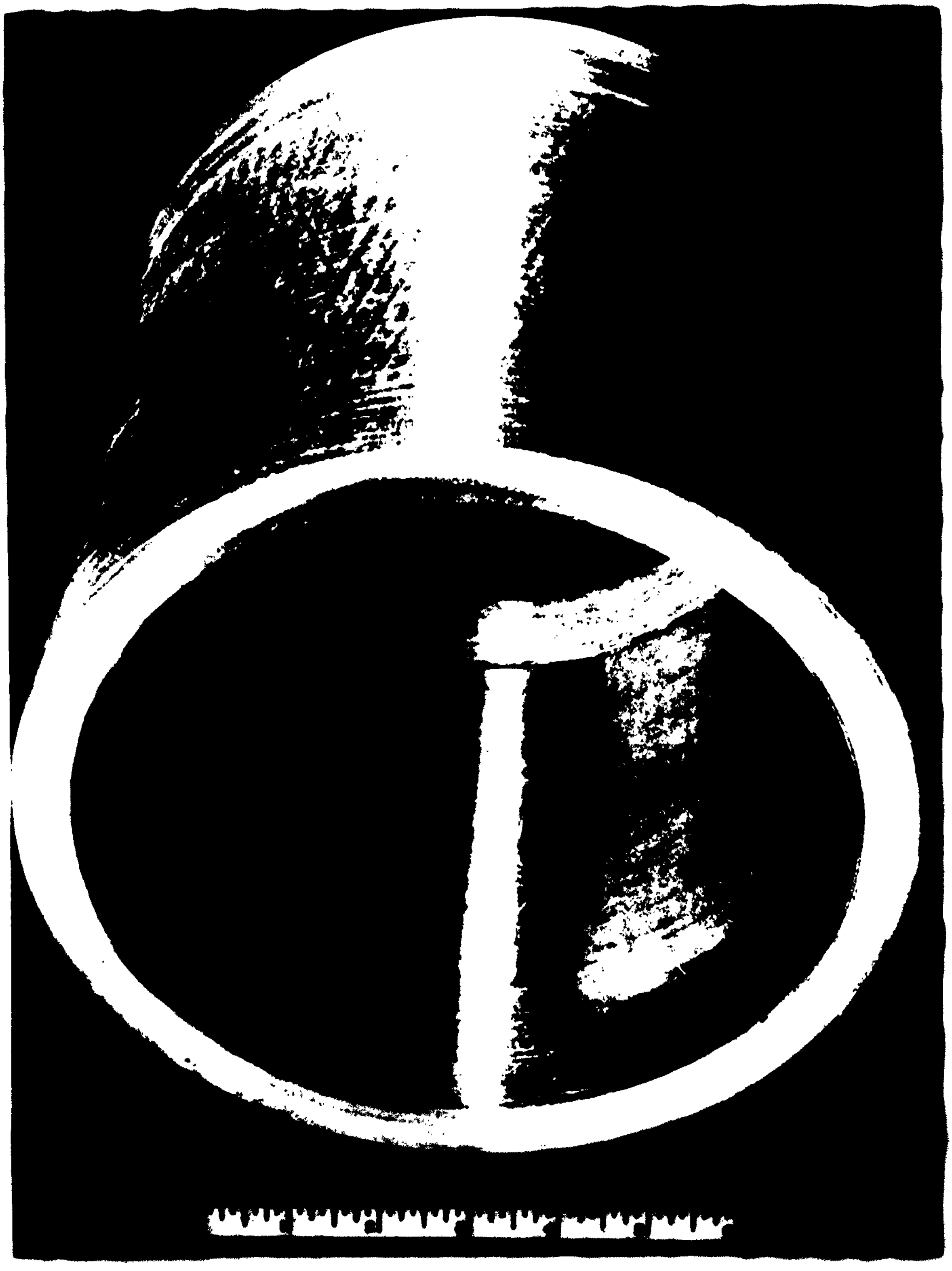


Figure 6. Delamination Between Inner Skin and Honeycomb Core

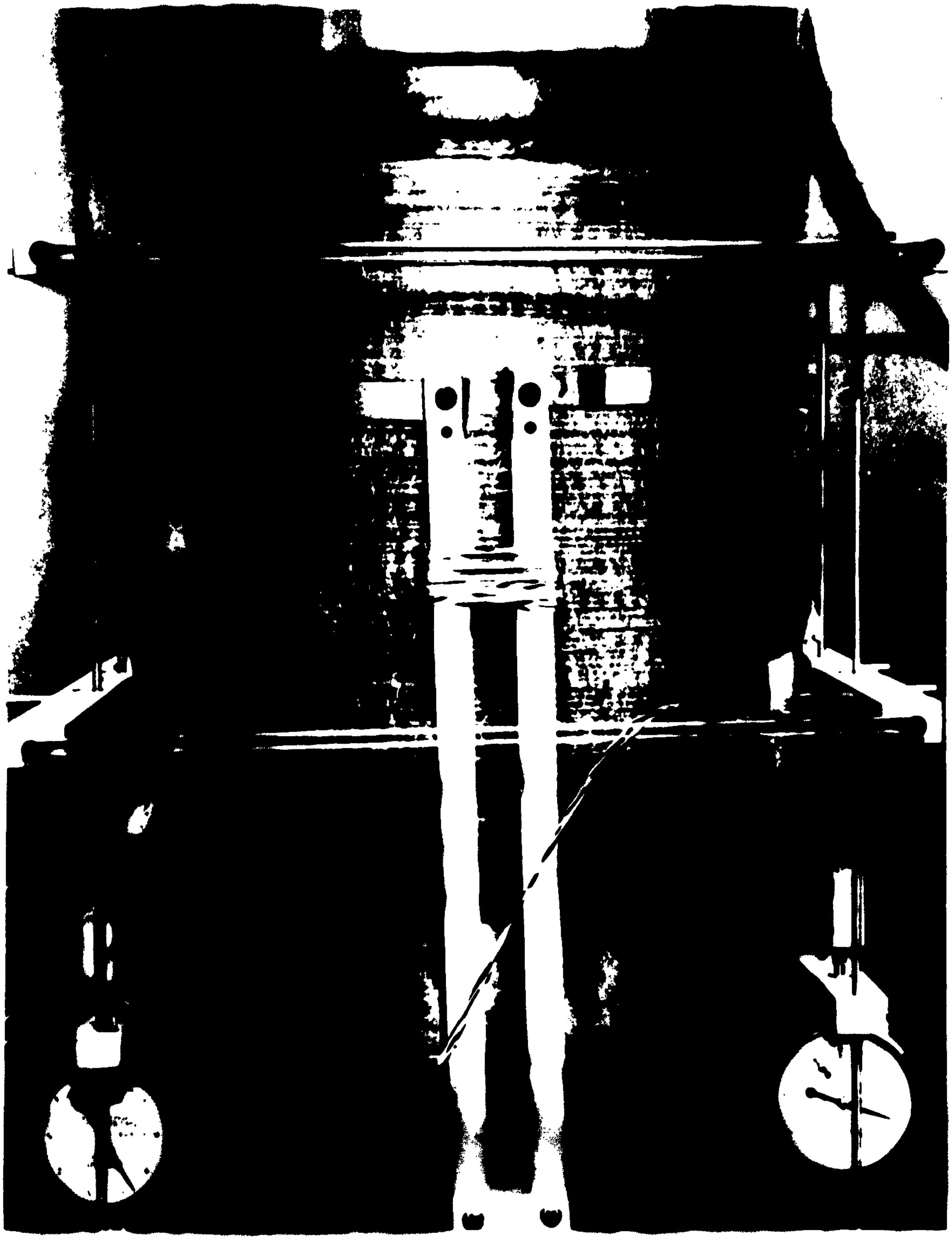


Figure 7. Detail of Sandwich-Wall Cylinder Test Setup

Figure 8. Segmented Sandwich-Wall Cylinder

II. PHASE II SUBSCALE CASES

OBJECTIVES AND DESCRIPTION OF SUBSCALE CASES

Six subscale filament-wound fiberglass rocket motor cases have been built and tested. The primary objectives of this study phase were to verify analytical methods and to perfect the manufacturing techniques to be used for fabricating the full-scale motor cases that will be built in phase III of this program.

A drawing typical of the configuration of the first 2 subscale cases is shown in Figure E-1. A drawing typical of the last 2 subscale cases is shown in Figure E-2. Many changes were incorporated into the drawing as manufacturing and testing of the subscales proceeded. These changes are described in the following paragraphs.

The subscale cases were designed to minimize the possibility of failures in the dome region; therefore, the dome was over-designed. The radius of the subscale cases is about one-half the radius of the full-scale cases. The facings and core depth of the sandwich in the subscale cases are the same as those to be used in the full-scale case. These dimensions could not be scaled down due to manufacturing limitations. The design-ultimate, internal pressure for the subscale cases (viz., 860 psi) results in approximately the same facing stress levels as in the full-scale case when it is pressurized to its design-ultimate, internal pressure of 405 psi. However, the polar wrap of the subscale case is only 7 degrees, while the full-scale wrapping angle is about 17 degrees. The angle of wrap was smaller for the subscale case because the polar fitting used for the subscale was the same one used for ABL cases built previously at Rocketdyne.

TESTING PROCEDURES FOR SUBSCALE CASES

Internal Pressure Test

The subscale motor cases which were pressurized internally were tested using hydrostatic pressure. A rubber bladder was placed in the subscale cases to prevent leakage. The specimen was placed vertically on a test stand and pressurized from the bottom. Two specimens were instrumented with strain gages as shown in Figure 9 and two others did not have gages. Three subscale cases were subjected to uniformly-increasing internal pressure to failure and one was pressurized in increments to failure. A summary of the method used to test each specimen and test results are presented in Table 3. Typical strain gage data are shown in Figures 10 and 11.

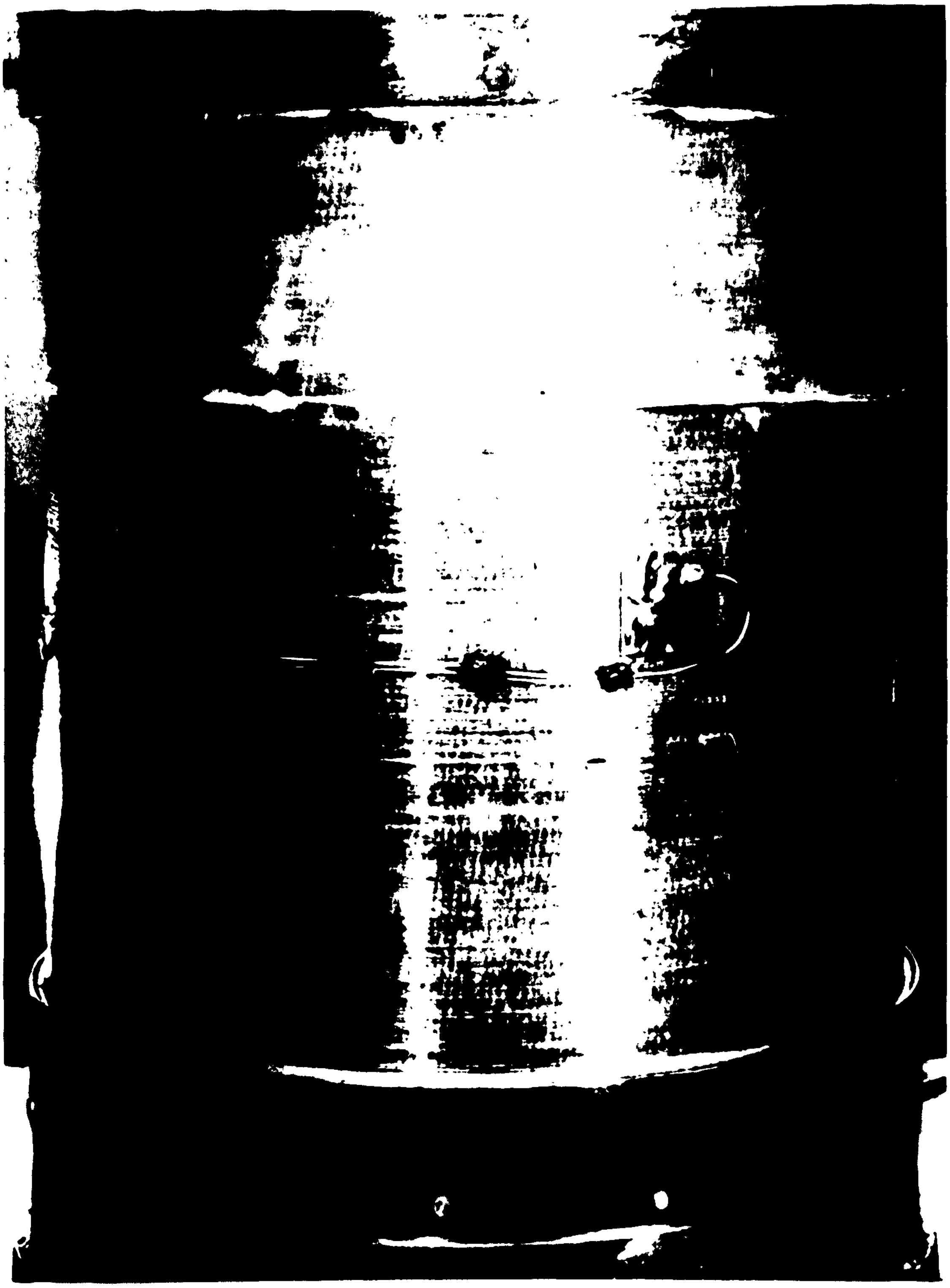


Figure 9. Subscale Case 2 after Failure

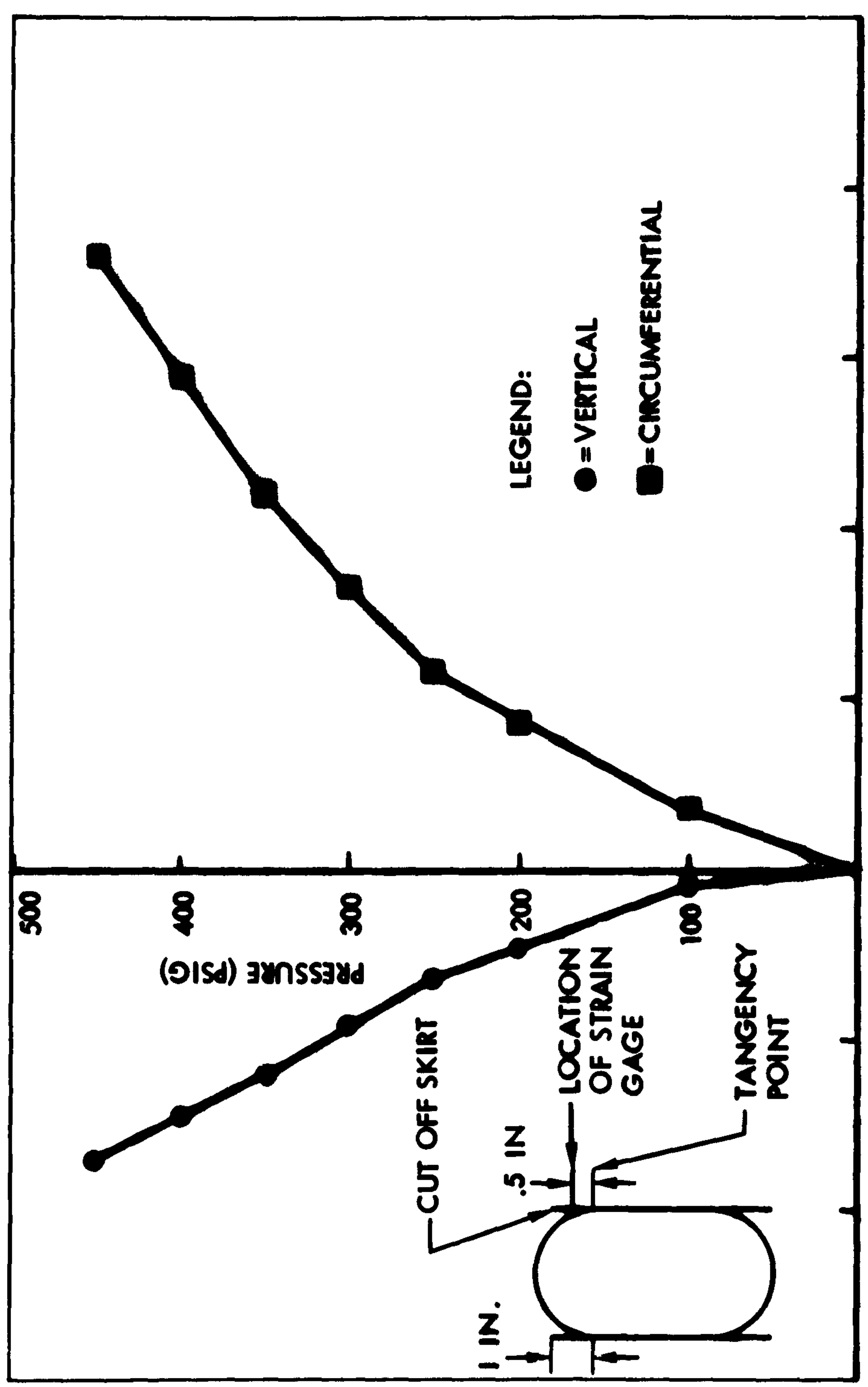


Figure 10. Strain Gage Data for Subscale Case 1 Skirt

Table 3. Summary of Subscale Test Results

Case No.	1	2	3	4	5	6
Type of Loading	Internal Pressure	Axial Compression	Internal Pressure	Axial Compression	Internal Pressure	Internal Pressure
Ultimate load	495 psi	103,000 lb	670 psi	78,000 lb	550 psi	940 psi
Approximate stress in longitudinal wraps due to membrane forces at ultimate load (psi)	70,000		95,000		62,000	108,000
Approximate stress in circumferential wrap at ultimate load (psi)	93,000		126,000		96,000	156,000
Average stress in longitudinal direction at ultimate load (psi)		22,400		17,400		
Approximate modulus of elasticity of composite in circumferential direction (psi)	5.5×10^6					
Approximate modulus of elasticity of composite in longitudinal direction (psi)	4.3×10^6	5.5×10^6		6.0×10^6		
Method of loading	50 psi increments	10,000 lb increments	uniform loading to failure	10,000 lb increments	uniform loading to failure	uniform loading to failure
Instrumentation	strain gages	strain gages	none	strain gages	none	strain gages

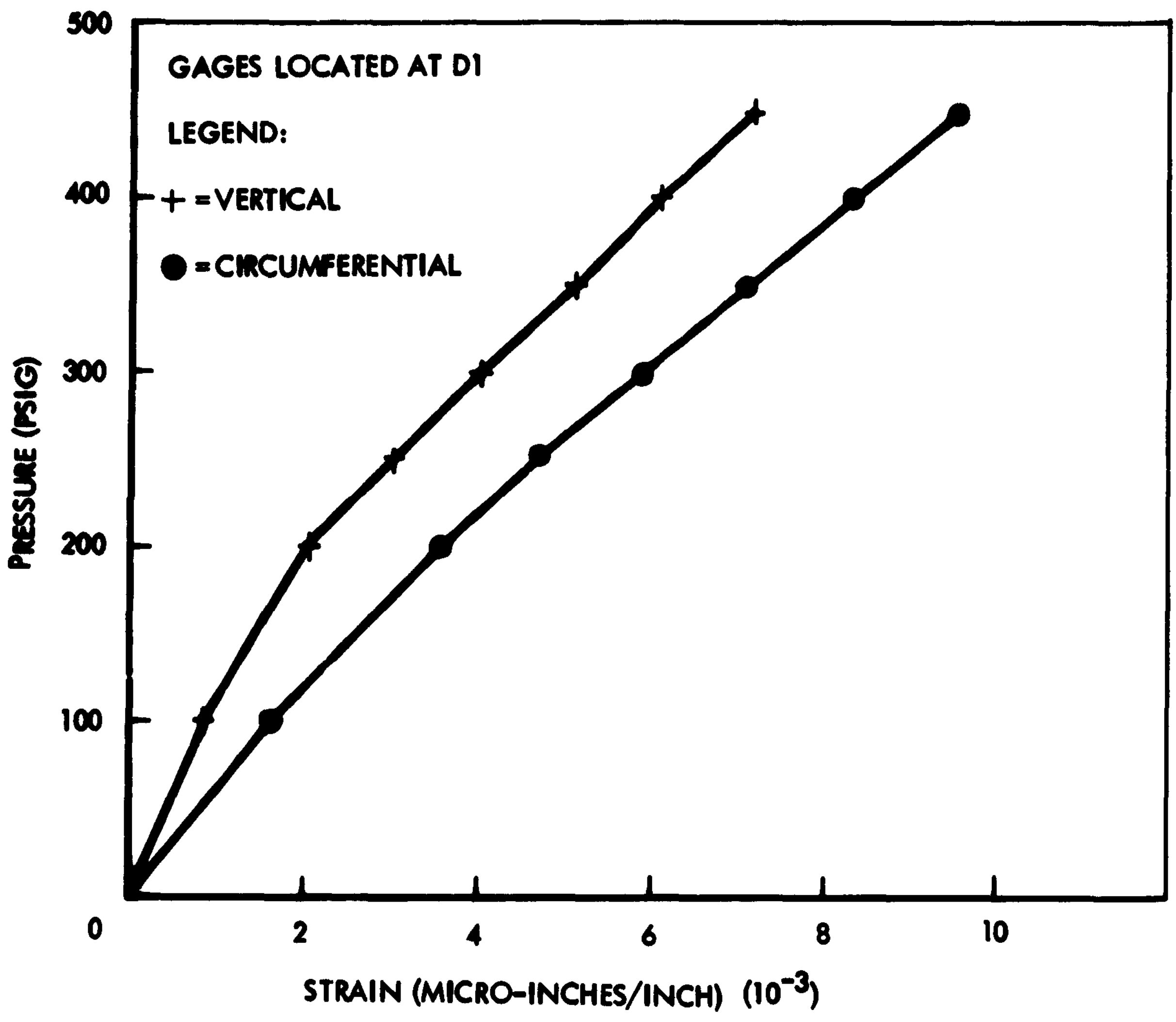


Figure 11. Strain Gage Data for Subscale Case 1, Location D1

Compression Test

The 2 subscale cases tested in axial compression were instrumented with a strain gage, as illustrated in Figure E-3. The ends of the specimen were cast in a ring with epoxy resin and the head of the test fixture was self-aligning to insure uniform load distribution. A Riehle 200, 000-pound testing machine was used. (The test fixture is shown in Figure 12.) The specimens were loaded in 10, 000-pound increments and strain gage readings were recorded for each increment of load. A summary of the test results is given in Table 3. Typical strain gage data are presented in Figures 13 through 19.

Photoelastic Studies

The modulus of conventional plastic laminates can be determined by established strain-recording devices. Fairly accurate approximations of filament-wound monocoque cylinders, which can be loaded by internal pressure, can be determined by recording load-strain data at the control area of the cylinders. Accurate load-strain data can be recorded for filament wound N. O. L. ring specimens. It is impossible, however, to determine the actual modulus of the filament-wound facings of sandwich-type cylindrical structures.

A study was instituted to endeavor to evaluate strain distribution in the plastic materials by means of the photoelastic coating technique. Reasonable correlations had been determined on metal parts by this technique. In these instances, the modulus of the base materials were known. Sandwich cylinder 5 was chosen to determine a method of applying the materials to the plastic background. A low-modulus photoelastic material was chosen for the test so that its modulus would more nearly match the modulus of the plastic sandwich facings. The photoelastic film was successfully mounted to the sandwich cylinder, but the reflective qualities of the bonding media did not produce a good spectral image. Sections of cylinders previously tested were used to improve the technique, and the bonding media was revised to produce better reflectivities.

Subscale case 1 was chosen for further photoelastic evaluation because the absence of one skirt made a large area of the dome accessible for strain distribution studies. The photoelastic material was successfully formed to the double contour necessary to fit the dome, but serious problems were encountered when trying to hold the material in intimate contact with the dome while the bonding agent set up. The dome laminate was permeable, an the vacuum bagging technique employed to maintain bonding pressure proved inadequate. It was proposed to strip the material and apply an impermeable coating before reapplying new photoelastic material. The assurance of success was minimal. Therefore, the case was tested without taking photoelastic readings. The strain gages that had

applied to the dome for comparison of stress flow patterns produced reasonable data. The project engineer of the Aeronautical Systems Division was therefore contacted with respect to the problems being encountered, and a decision was made to omit further effort with photoelastic materials.

The photoelastic material which was applied to subscale case 1 can be seen in Figure 20. The dome failed in the area where the photoelastic film was applied but the failure was not attributable to the film or process of application.

TEST RESULTS OF SUBSCALE CASES

The test results of subscale cases are summarized in Table 3. A description of each is presented in the following paragraphs.

Subscale Case 1

Subscale Case 1 failed at an internal pressure of 490 psi. The failure is shown in Figure 20. The longitudinal fibers of the inner facing failed in tension at a point 3 inches below the tangency point of the dome and cylinder. (This is just below the point where the second layer of longitudinal wraps on the dome is cut off.) It is believed that the longitudinal load from the dome did not redistribute itself between the 2 facings of the sandwich. Part of the longitudinal load should be transferred by shear through the core of the sandwich into the outside facing. The relatively large step in the longitudinal windings–resulting from cutting the second longitudinal wrap–causes a stress concentration in the first wrap which also may have contributed to the premature failures. If it were assumed that none of the longitudinal load transferred to the outside facing, the tensile stress in the inside longitudinal wrap at the time of failure was approximately 140, 000 psi.

Because of many difficulties encountered during fabrication, it was impossible to determine the exact cause of the premature failure. The bond between the core and the inside facing was found to be poor in the area of the failure, which may have been a reason for the poor shear transfer between facings. The specimen failed at the end of the case from which the skirt had been removed, and it is possible that the case had been damaged when attempts were made to remove the skirt tooling prior to removing the skirt.

The tension modulus of the case, as determined from the center of the cylindrical section, was about 5.5×10^6 psi in the circumferential direction, and 3.5×10^6 in the longitudinal direction.

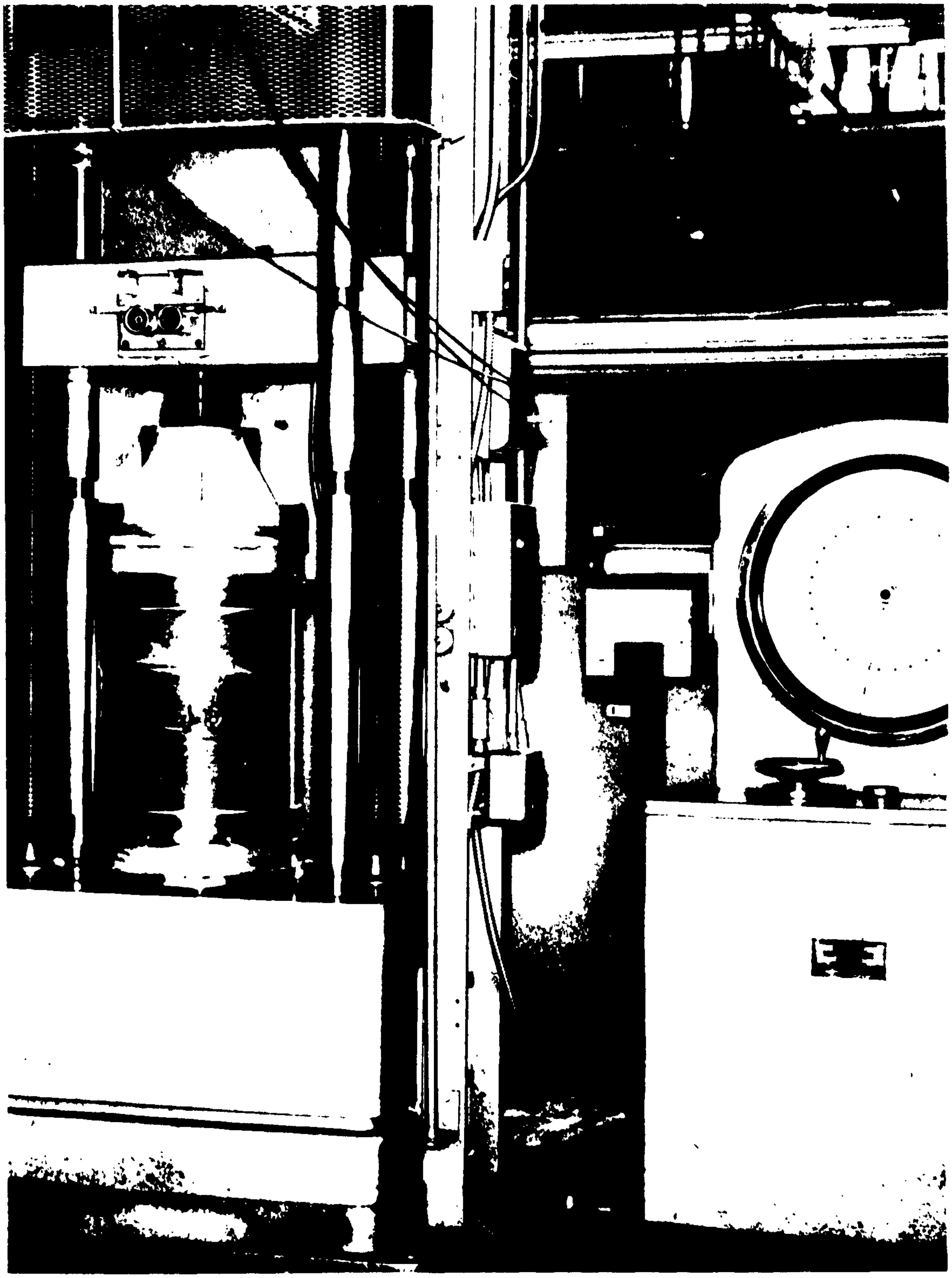


Figure 12. Subscale Compression Test Fixture

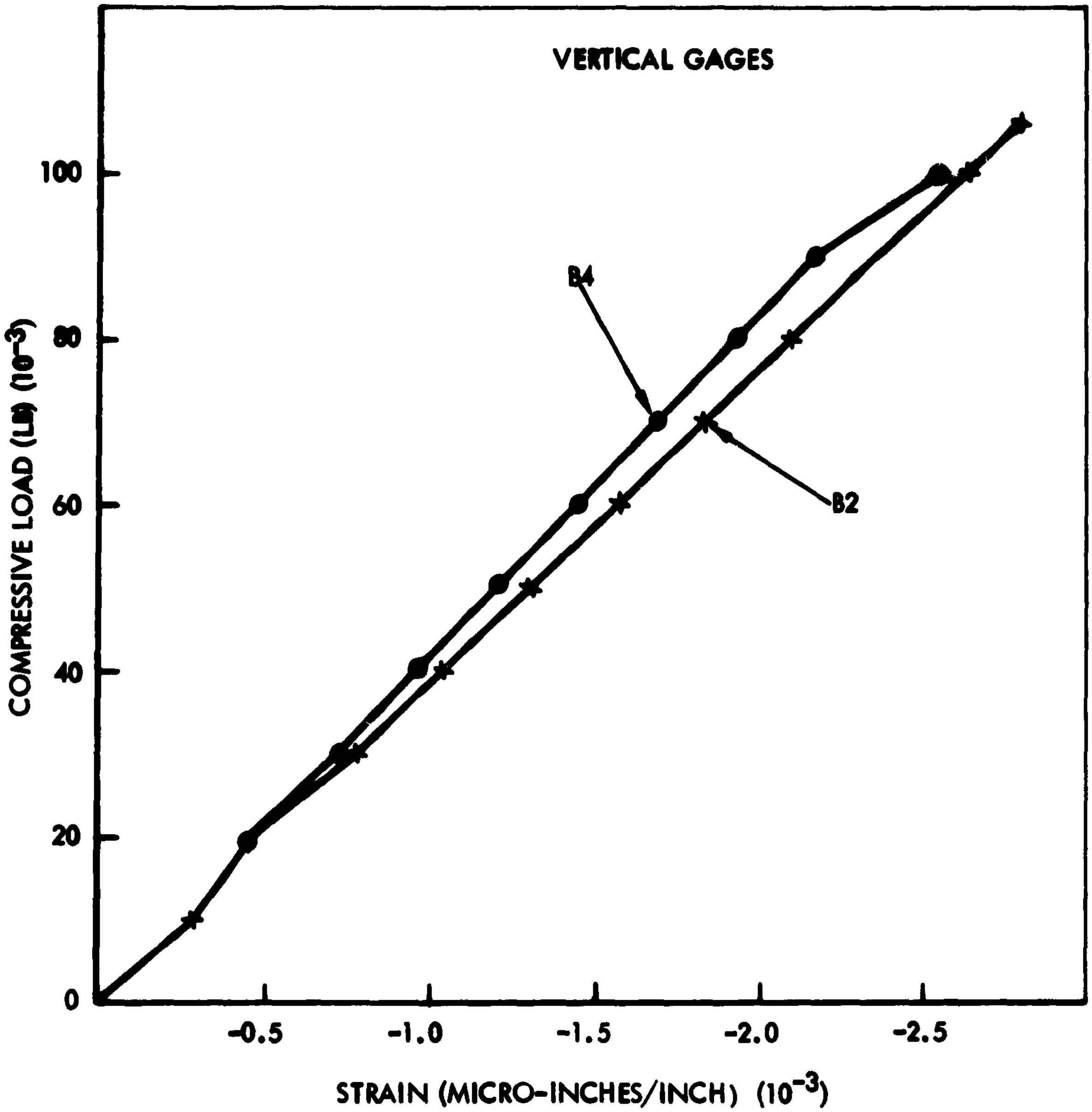


Figure 13. Strain Gage Data for Subscale Case 2, Location B

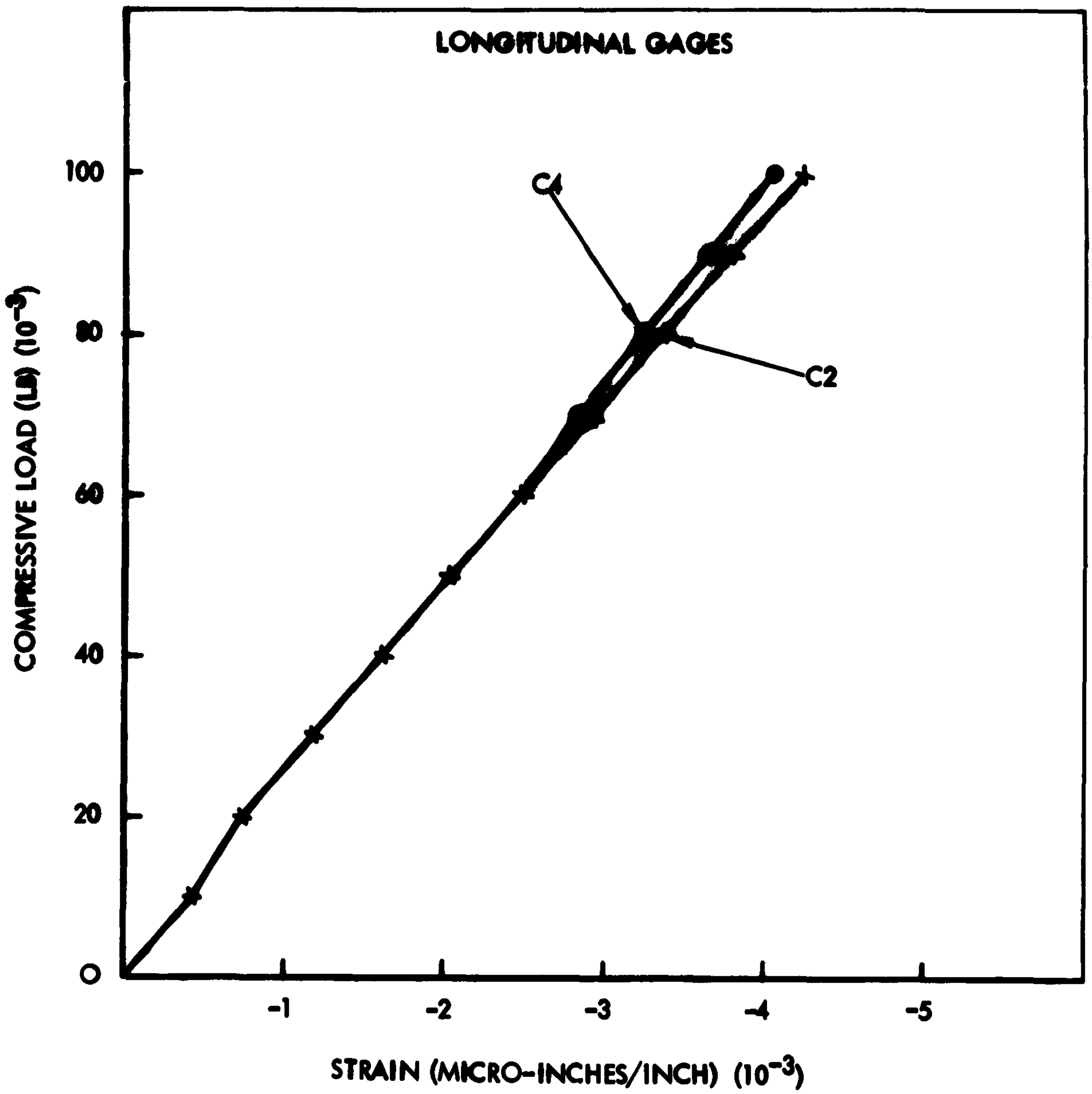


Figure 14. Strain Gage Data for Subscale Case 2, Location C

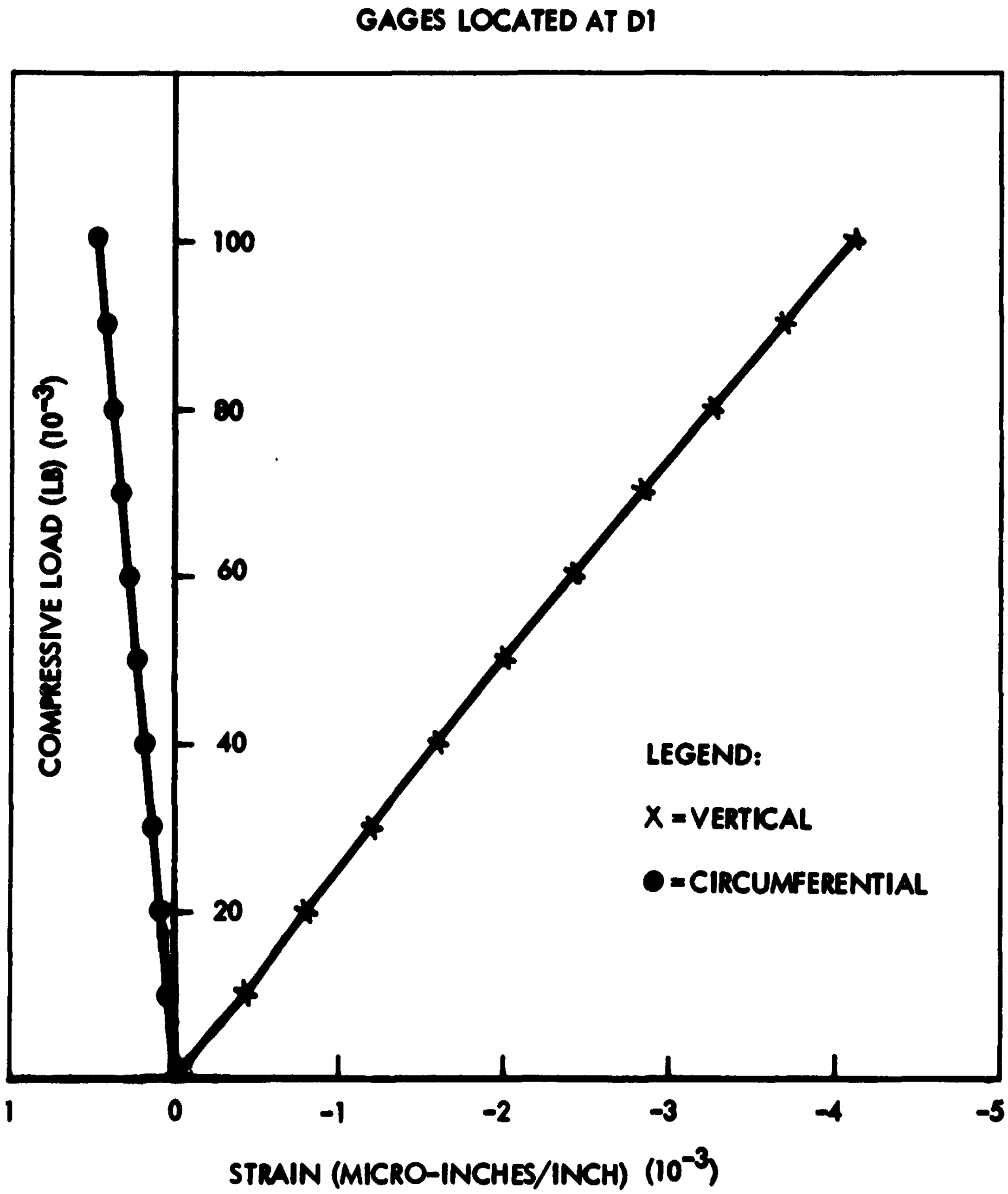


Figure 15. Strain Gage Data for Subscale Case 2, Location D1

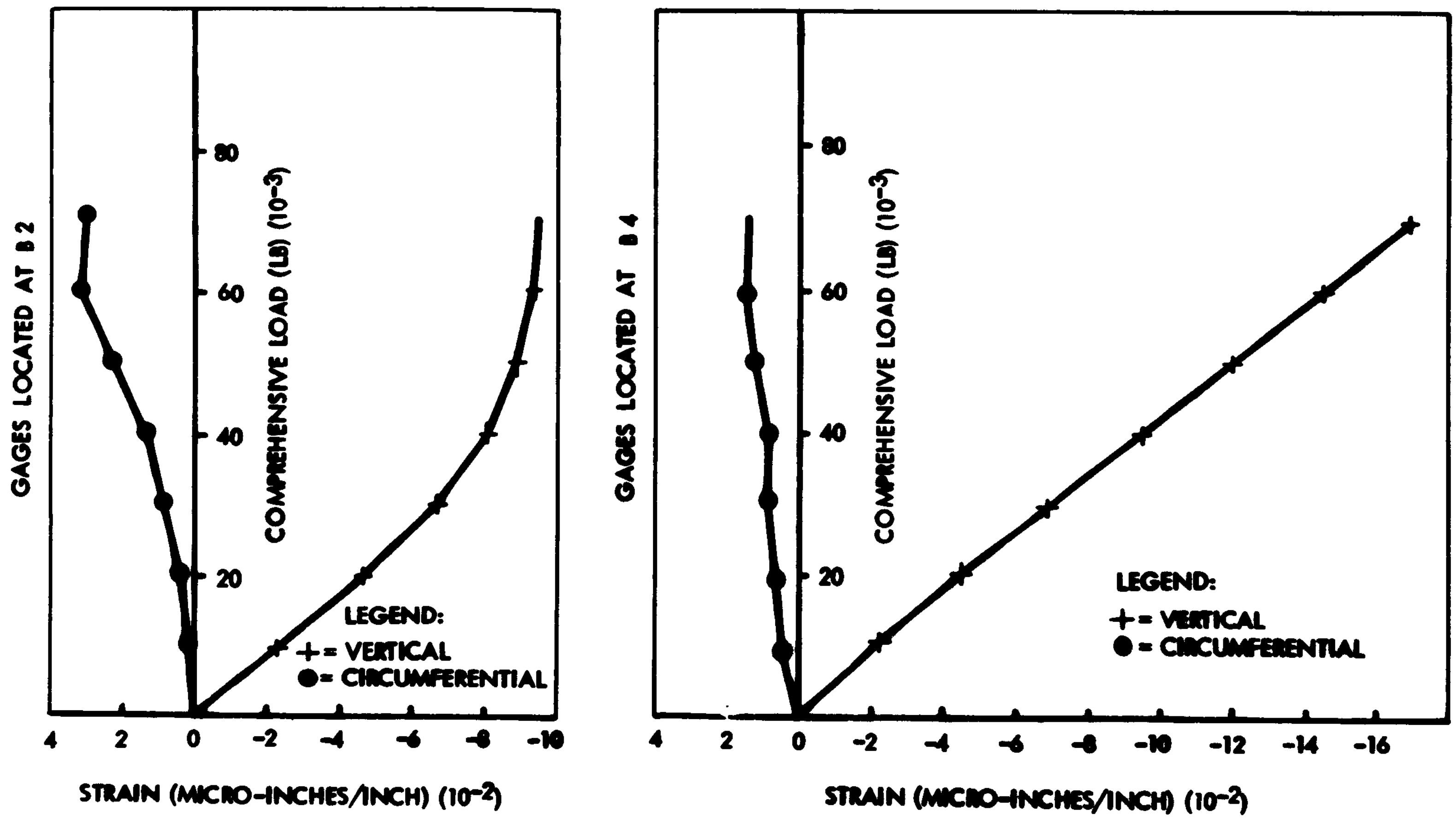


Figure 16. Strain Gage Data for Subscale Case 4, Location B

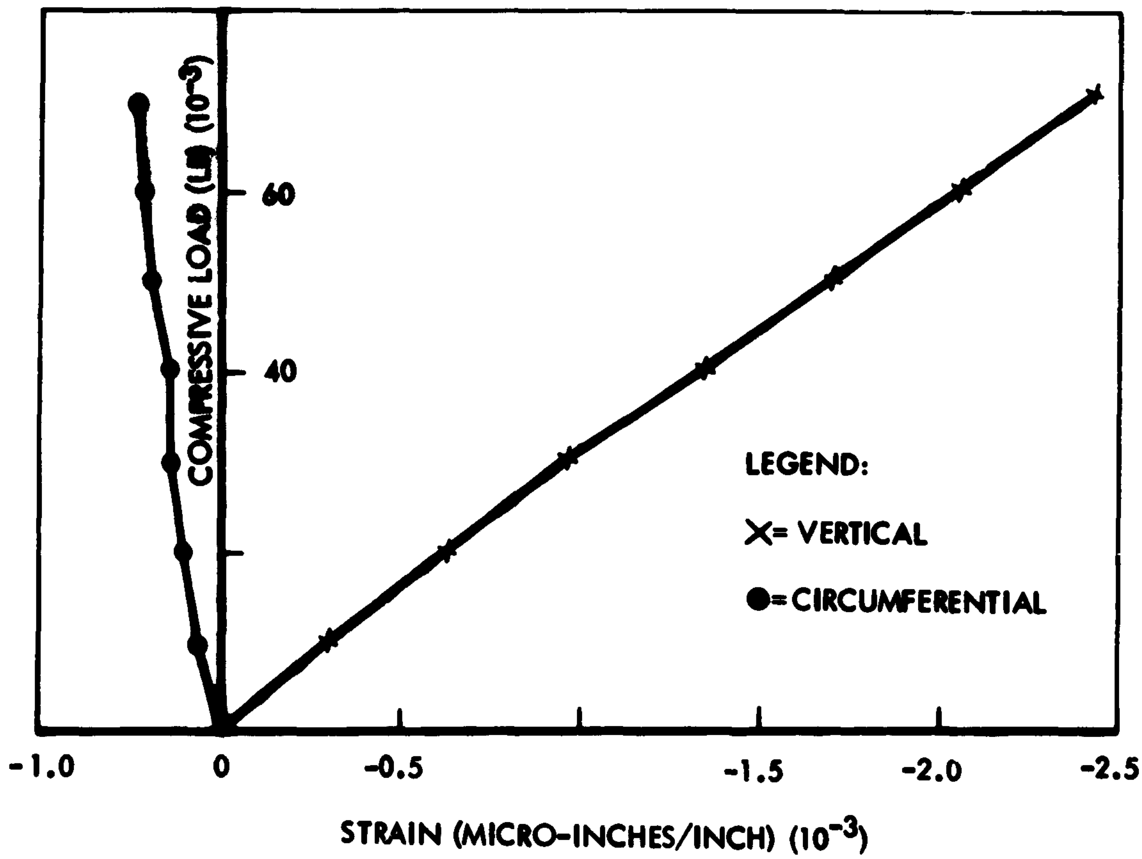


Figure 17. Strain Gage Data for Subscale Case 4, Location C2

GAGES LOCATED AT C4

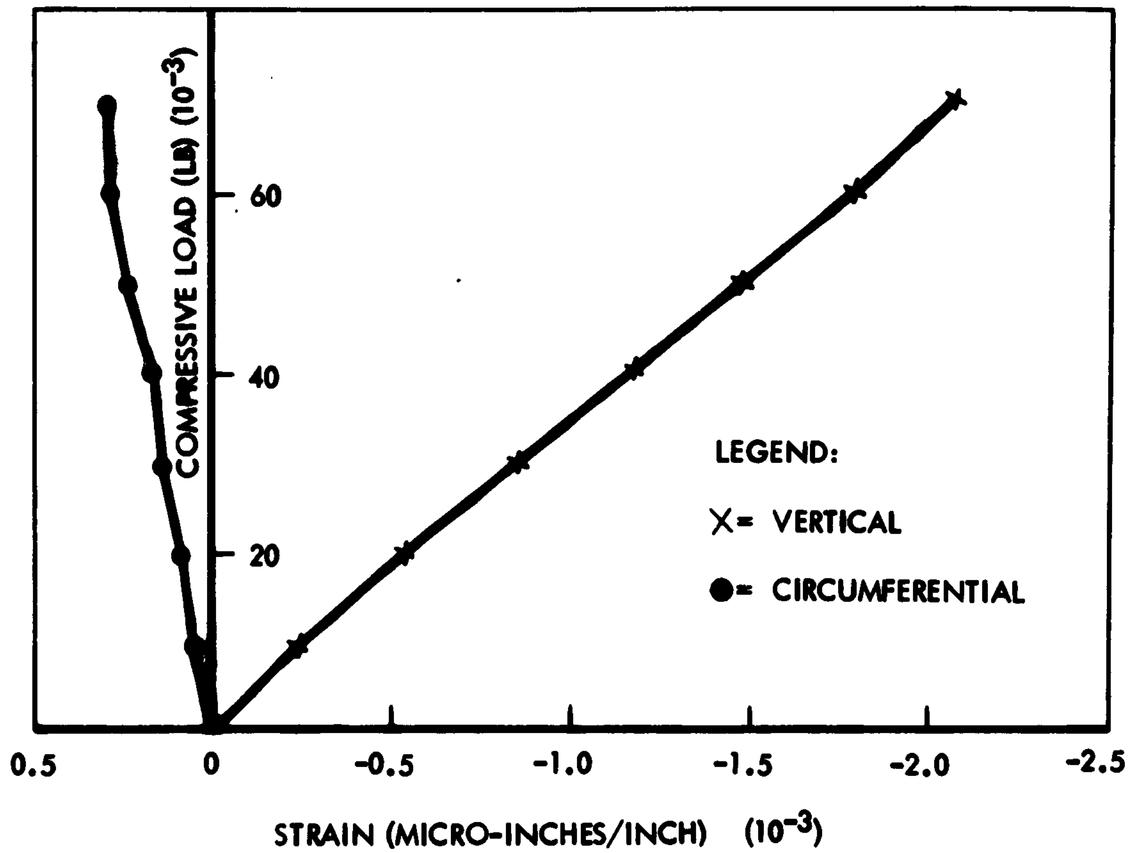


Figure 18. Strain Gage Data for Subscale Case 4, Location C4

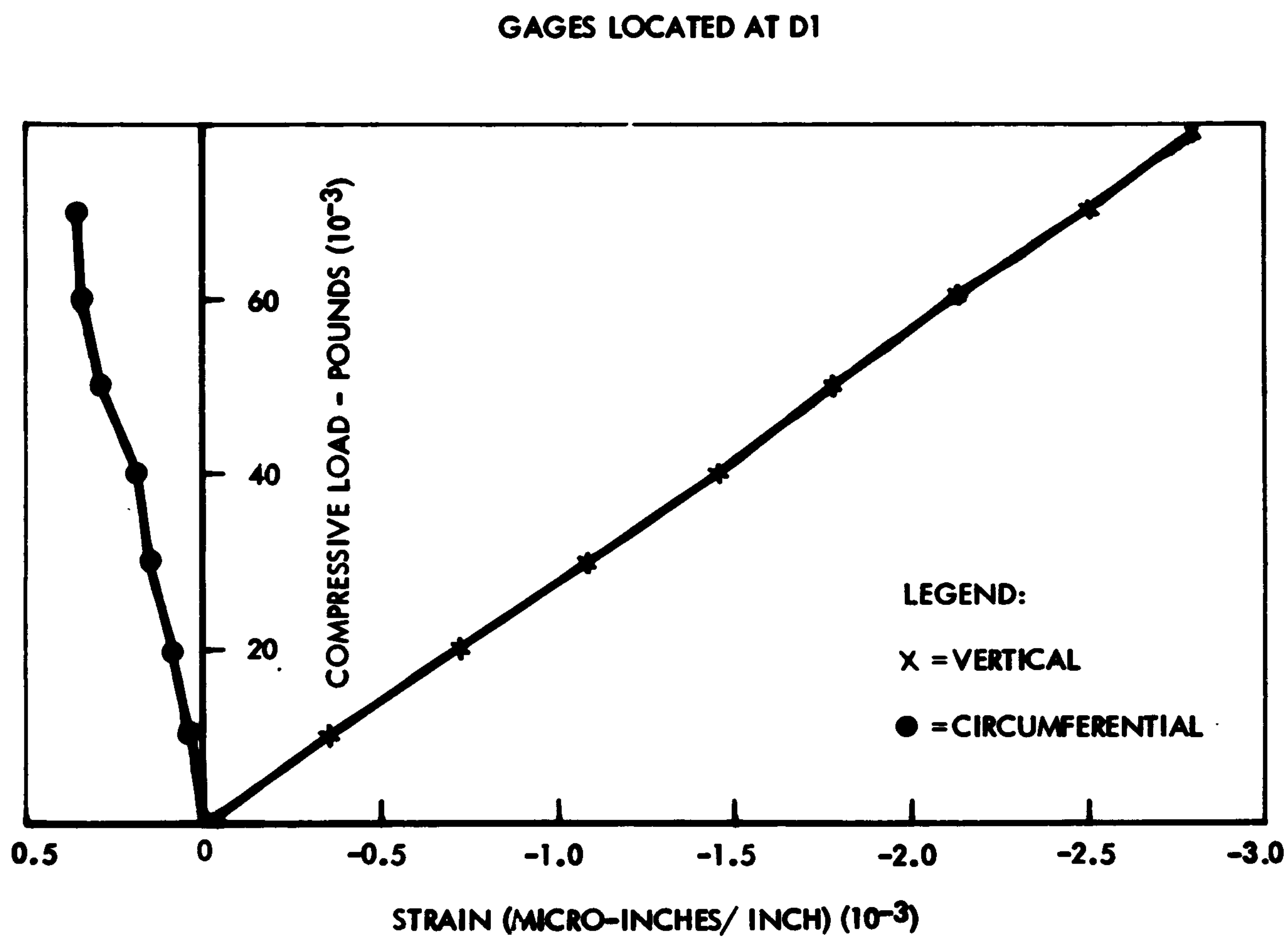


Figure 19. Strain Gage Data for Subscale Case 4, Location D1

Figure 26. Subscale Case 1 after Failure

Subscale Case 2

The second subscale case was tested in axial compression and failed at a load of 106,000 pounds. The average compressive stress at failure was approximately 23,000 psi. If it were assumed that the longitudinal fibers took all the load, the compressive stress in the longitudinal fibers at failure would have been 70,000 psi. The failed specimen is shown in Figure 21. The failure occurred just below the reinforced area near the tangency point. The ultimate failure occurred very abruptly, although fiber could be heard popping from 50,000 pounds on up to ultimate failure.

It is believed that the failure was a fiberglass facing-material compression failure. The ultimate stress level was approximately the same as the ultimate compressive stress level achieved in the 8-inch sandwich cylinders. Since the calculated allowable buckling stress of the cylinder is approximately 32,000 psi, it is unlikely that the cylinder had buckled.

The compressive modulus of the case, as determined from the center of the cylindrical section, was approximately 3.2×10^6 psi in the longitudinal direction.

Subscale Case 3

Subscale case 3, which was a pressure specimen, was tested without strain gages to obtain the test results quickly, so that any necessary design changes could be incorporated into subsequent subscale cases. The internal pressure was gradually increased to 670 psi, which is the design-proof pressure, and an attempt was made to hold this pressure for 5 minutes. However, after about 1 minute, the longitudinal windings in the inside facing failed in the same area as in subscale case 1 and the dome pulled out of the cylindrical portion of the tank, as shown in Figure 22. Several loud cracking sounds were heard at pressure less than 670 psi, but no visible damage was noticed on the outside of the subscale cases. When the subscale case was dissected, it was found that the inside facing sheet had failed in circumferential tension in the same area where the longitudinal windings failed; this is shown in Figure 23. It was also found that the core, between the two facing sheets in the area of the core splice, had failed in shear.

It is difficult to determine which failure occurred first; however, it is probable that the following sequence of failure occurred:

It is believed that a progressive failure of individual circumferential windings in the inner facing sheet occurred first, because, as the pressure passed 600 psi, many internal failures could be heard. The hoop stress at 600 psi internal pressure is about 110,000 psi. It was found that the circumferential windings failed in an area with wrinkles in the inside facing, before

testing, as has previously been described. These wrinkles probably resulted in the low ultimate strength. When the circumferential windings broke, the core had to withstand all the internal pressure and it was crushed, as can be seen in Figure 24. It was then necessary for the outside facing to absorb all of the circumferential loads. The stress level in the circumferential direction of the outside facing, at a pressure of 670 psi, would then be about 250, 000 psi.

This is commensurate with tensile stresses which have been reached by some burst specimens. These high stresses resulted in large circumferential strains in the case and failed the core in shear (see Figure 25) due to discontinuity stresses between the skirt and the pressurized cylinder. When the core failed in shear, all the longitudinal load from the dome had to be routed in the inside longitudinal wrap which failed at a stress of about 190, 000 psi.

Subscale Case 4

Subscale case 4 was a compression specimen and was tested under the same condition as subscale case 2. Before testing, the delaminated area previously mentioned was marked and watched during the test. At a load less than the ultimate load of the specimen, this area buckled outward, but the specimen continued to take additional load. At a load of 78, 000 pounds, a small area of the cylinder buckled inward. This buckle failure was in the unreinforced area of the cylindrical portion of the tank diametrically opposite to the external delaminated area and immediately adjacent to the filled core. This failure occurred at a stress of approximately 17, 600 psi (see Figure 26). The low ultimate compressive stress may have been due to delaminations or the wrinkles in the facings. A typical area is shown in Figure 26.

Subscale Case 5

Subscale case 5 was a pressure specimen and was not instrumented. The specimen contained evidences of wrinkling of the inner circumferential filaments. The filaments could be heard cracking from a pressure of 100 psi to 570 psi when the test was stopped. The test was stopped because the internal pressure was decreasing without visual evidence of tank failure. It was concluded, at that time, that the bladder had leaked. However, subsequent inspection of the inside of the tank indicated that a large area of the inside facing had failed in hoop tension. The failure occurred in a wrinkled area of the inside facing (see Figure 27).

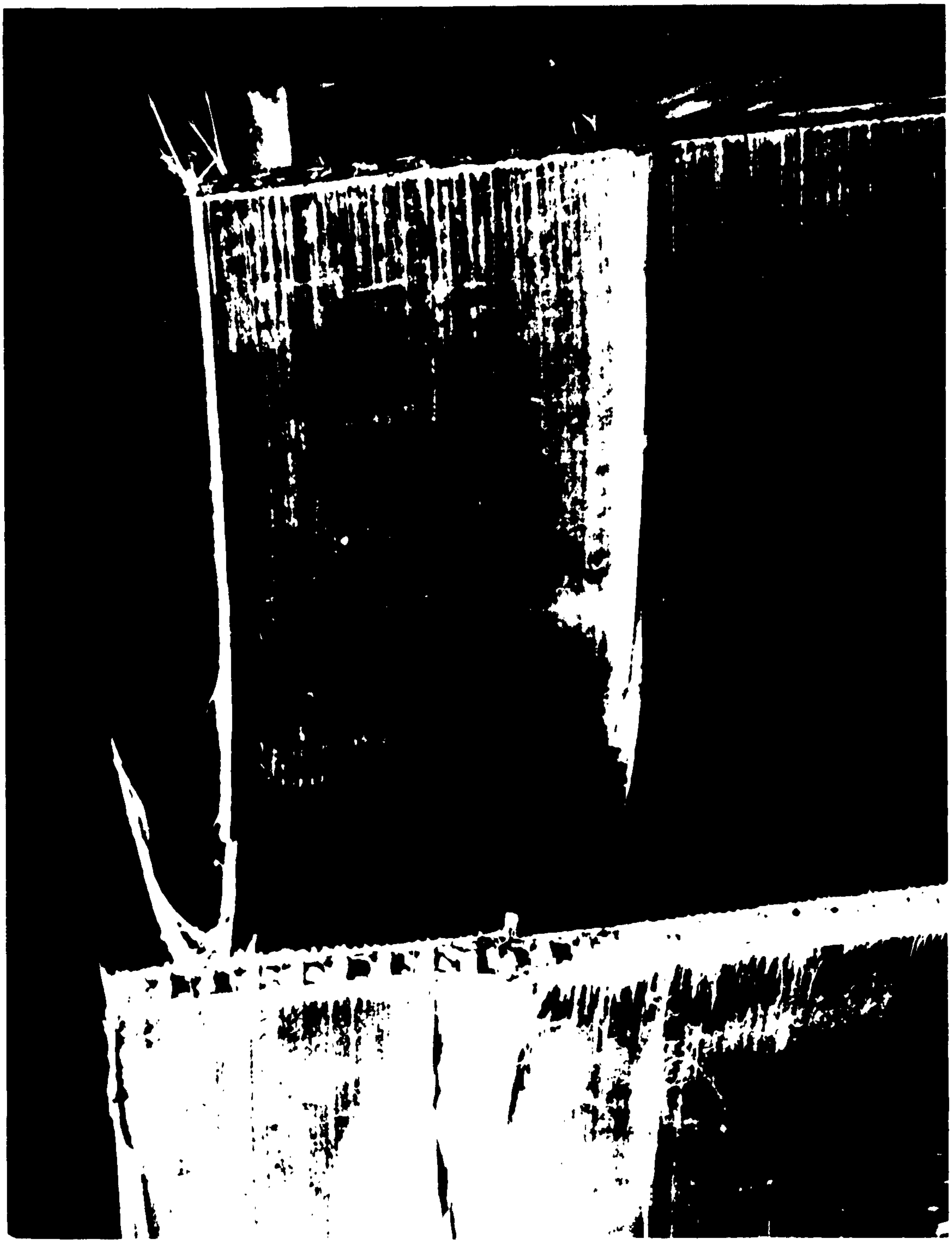


Figure 21. Subscale Case 2 after Failure

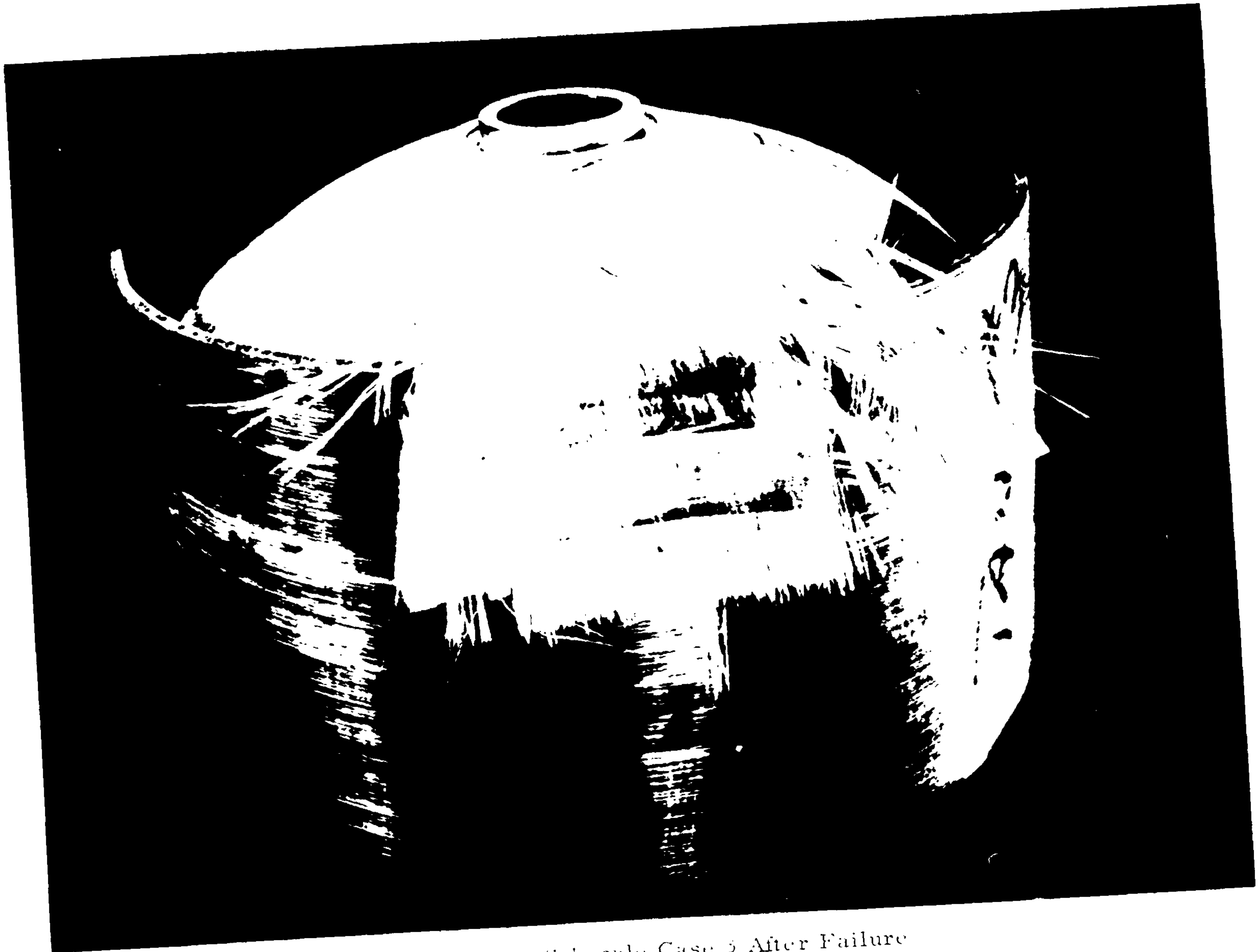


Figure 22. Subscale Case 5 After Failure

Figure 23. Failure of Circumferential Winding in Subscale Case 3

Figure 24. Crushed Core of Subscale Case 3

Figure 25. Subscale Case 3, Shear Failure of Core

Figure 26. Subscale Case 4 After Failure

Figure 27 Circumferential Winding Failure in Subscale Case 5

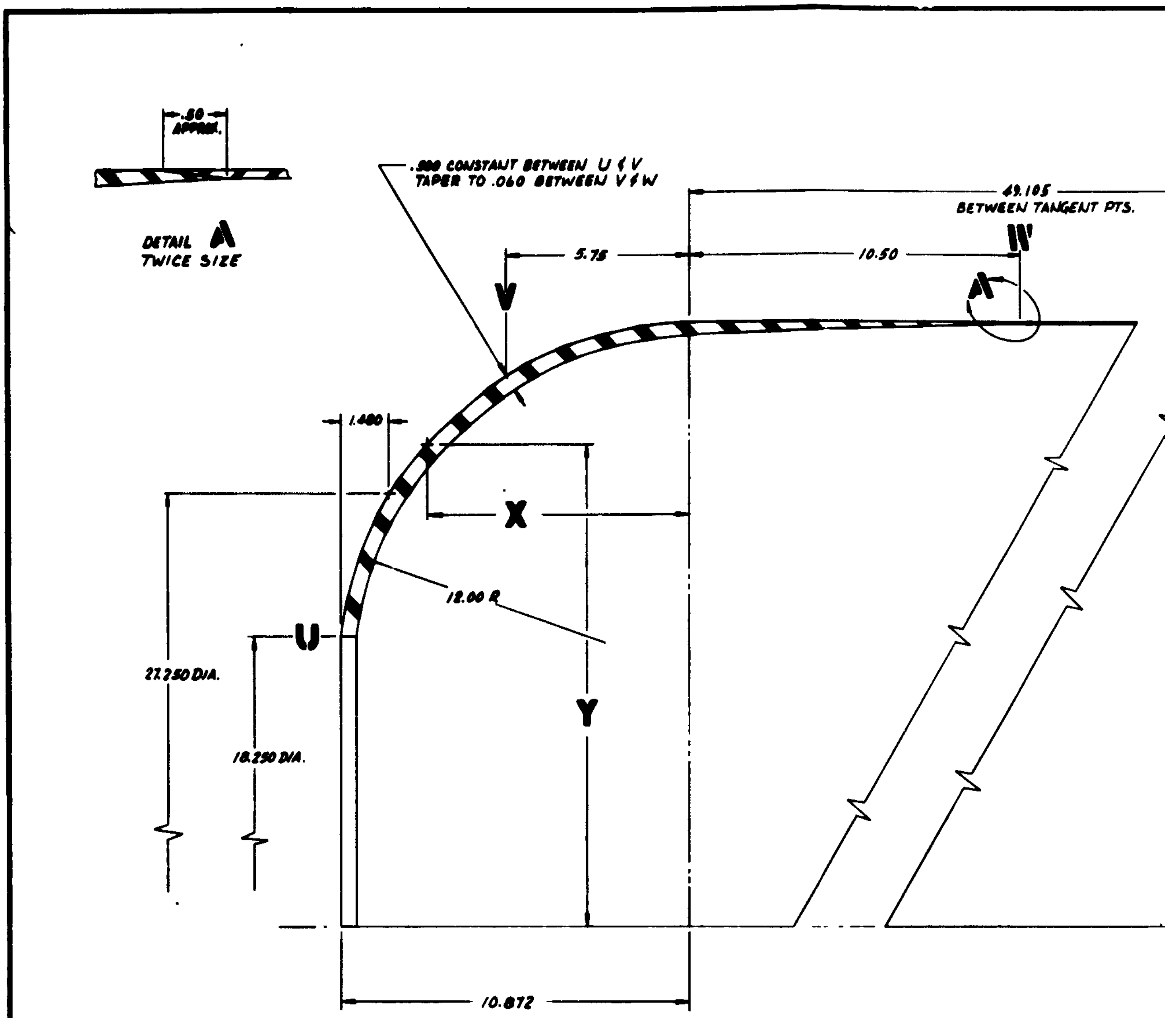
III. DESCRIPTION OF FULL-SCALE MOTOR CASE

The design of the full-scale motor case is very similar to the design of the last 2 subscale cases. The primary difference is in the radius of the full-scale tank and the relative size of the polar opening. The inside radius of the full scale case is 19 inches, whereas the inside radius of the subscale is 8.94 inches. The ratio of the full-scale polar opening to the radius of the full-scale case is 0.58 whereas this same ratio for the subscale cases is 0.28. The facing sheet gages and the core depth of the sandwich is the same for the full-scale cases and the last two subscale cases. A drawing of the full-scale case is shown in Figure E-4. The dome used for this case is different from the subscale case because of the larger polar opening which was used.

It is currently proposed to purchase prefabricated liners for the motor cases which will be static fired and the motor case which will have environmental loadings. The proposed vendor is Reinhold Plastics, a division of the Haveg Corporation. The insulation for this full-scale case will be fabricated by the McGregor Division from a NAA proprietary material and will conform to the dimensions shown in Figure 28.

The nozzle design for the static-fired cases is shown in Figure 29. It is currently proposed to secure the prefabricated nozzle from an experienced vendor.

The full scale motor case was designed as the third stage of the booster for the escape mission described in AMC Interim Report 7-878 (I). The calculated loads and temperature for this mission were used in the structural analysis of the full-scale case. The limit internal pressure for the third stage motor is 300 psi. The gages of the sandwich facings, in the cylindrical portion of the case, which were used in the stress analysis are the same as those used in the first 4 subscale cases. These facing gages resulted in positive margins of safety in all sections of the cylindrical portions of the motor case. The facing gages to be fabricated for the full-scale cases have been increased to the facing gages of the last 2 subscale cases. This was the result of manufacturing difficulties which resulted in low failure loads of the subscale cases as described in a previous section of this report. If these larger facing gages were used in the stress analysis, larger margins of safety would result. The stress analysis of the full-scale case is presented in Appendix A.



X	Y
0.00	19.00
0.82	18.96
1.67	18.80
2.53	18.68
3.44	18.37
4.32	18.08
5.19	17.58
6.08	17.00
6.96	16.36
7.80	15.58
8.61	14.64
9.44	13.57

NOTE: UNLESS OTHERWISE SPECIFIED

Fi

ASD

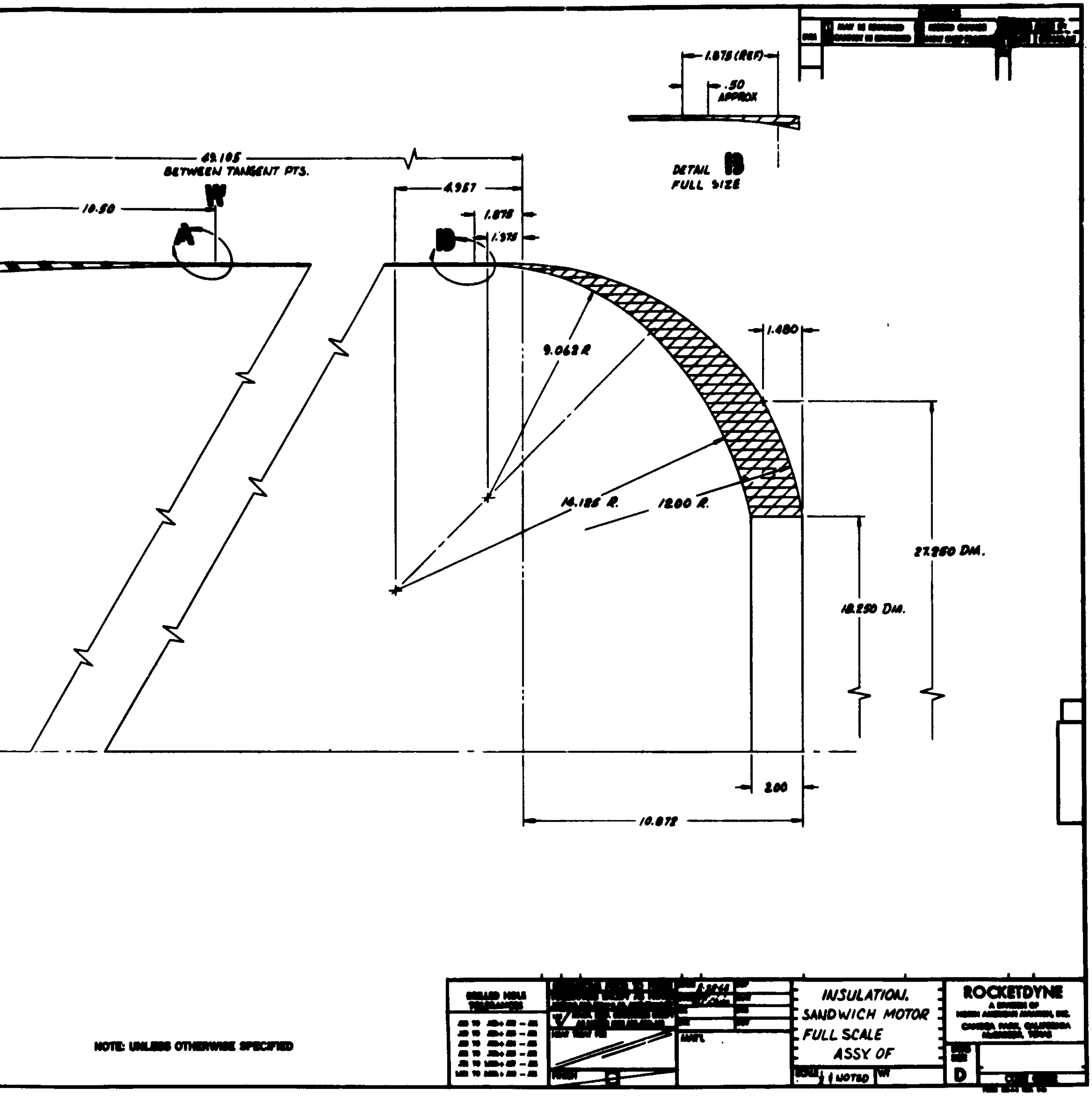
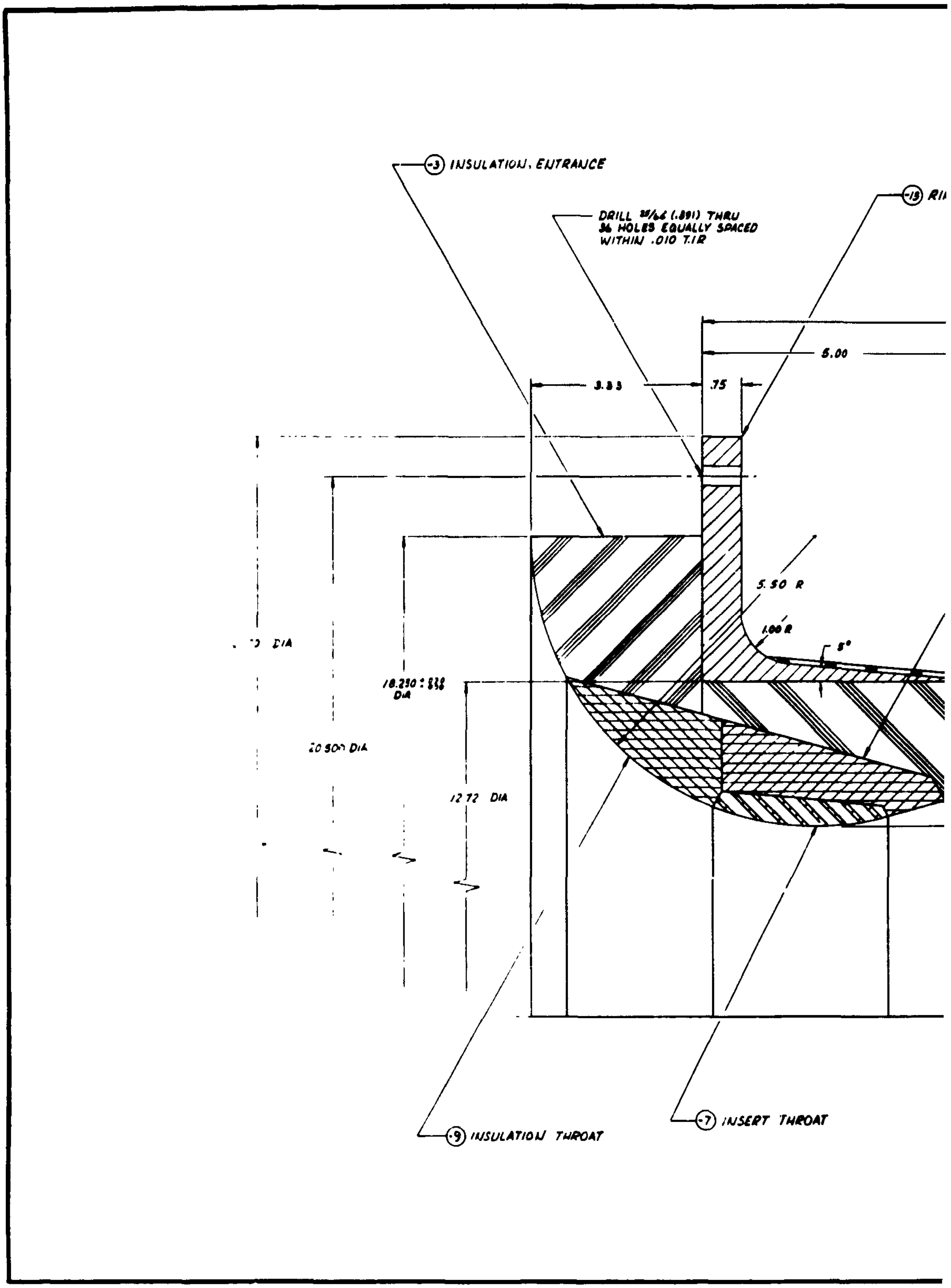


Figure 28. Drawing of Insulation for Full-Scale Sandwich Motor Case



-3 INSULATION, ENTRANCE
DRILL 57/64 (.891) THRU
36 HOLES EQUALLY SPACED
WITHIN .010 T.I.R
-13 RI
5.00
3.83
.75
5.50 R
1.00 R
5°
DIA
18.250 DIA
20.500 DIA
12.72 DIA
-9 INSULATION THROAT
-7 INSERT THROAT

1

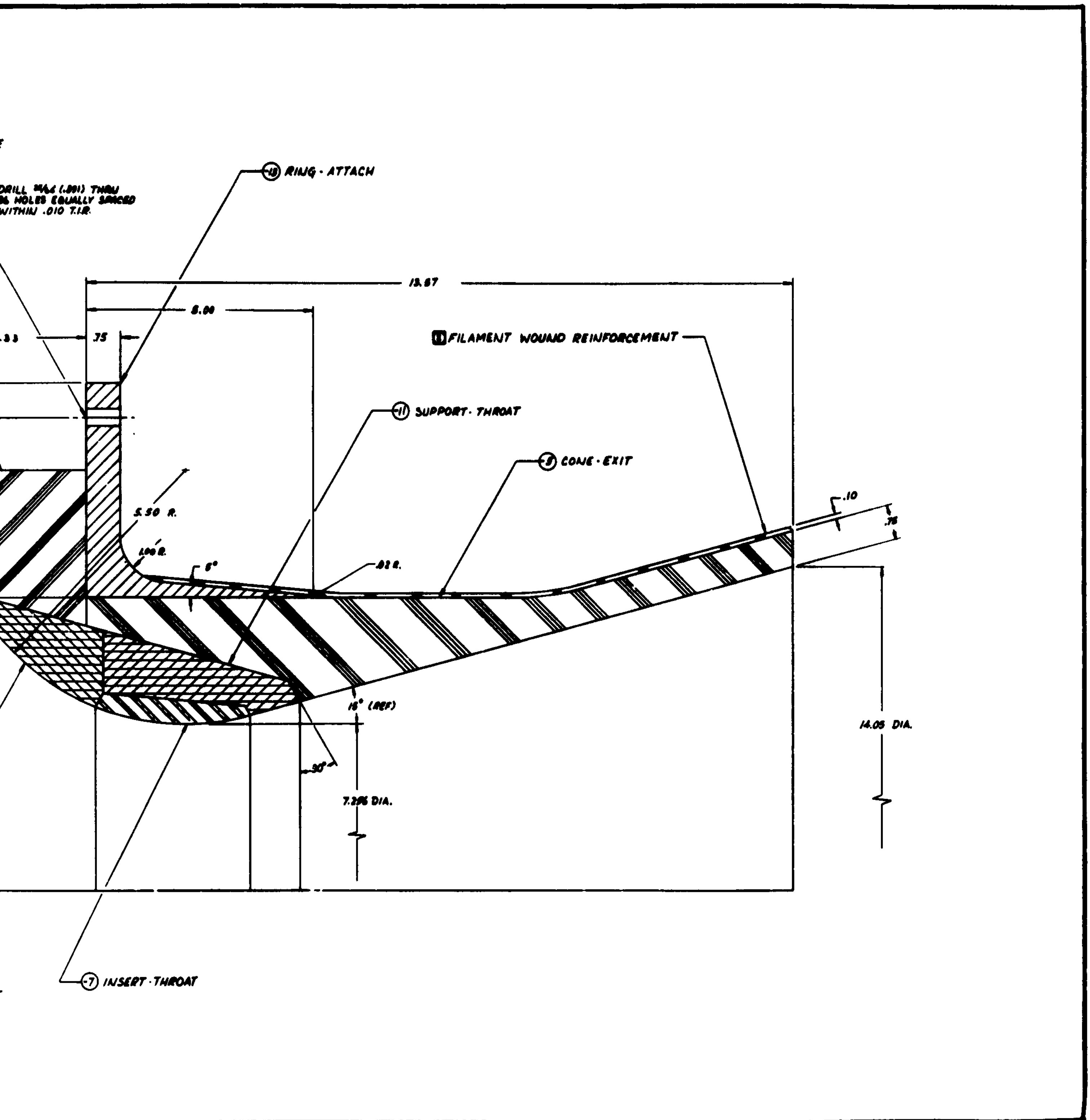


Figure 29. Drawing of Test Nozzle for Full-Scale Motor Case

IV. GENERAL FABRICATION PROCEDURES

Seven 8.5-inch diameter sandwich cylinders and 6 subscale sandwich rocket motor cases were constructed at the Rocketdyne Division. The variations in fabrication techniques are described in detail in this section, together with descriptions of the supporting process development studies required to construct a subscale sandwich motor case representative of the full-scale design.

SANDWICH-WALL CYLINDER FABRICATION PROCEDURES

Seven sandwich cylinders, 10 inches long by 8.5-inch inside diameter and with 1/2 depth Multiwave core, were fabricated (See Figure 5).

Sandwich-Wall Cylinders 1 and 2

The following fabrication sequence and procedure were typical for assemblies 1 and 2:

The mandrel was coated with a heat resistant parting agent, cured at 350° F and subsequently coated with two applications of Carnauba wax.

One circumferential layer of roving, impregnated to 18 ±2 percent resin content with U.S. Polymeric E787 resin was applied over the entire length of the mandrel. The thickness was approximately 0.008 inches. A longitudinal layer, 0.014-inch thick and oriented at 16.5 degrees to the longitudinal axis (see Figure 30), followed. Two additional layers (0.016 inch total) of circumferential windings were then applied.

The end reinforcements and core-to-face adhesive were applied (see Figure 31) in the following manner:

1. At each end, strips of No. 143-style fiberglass cloth (impregnated with U.S. Polymeric E787 resin)—with the warp oriented in the longitudinal direction–and 0.008-inch circumferential windings were alternately applied (30 layers of No. 143 cloth and 29 circumferential wraps to form solid plastic inserts.

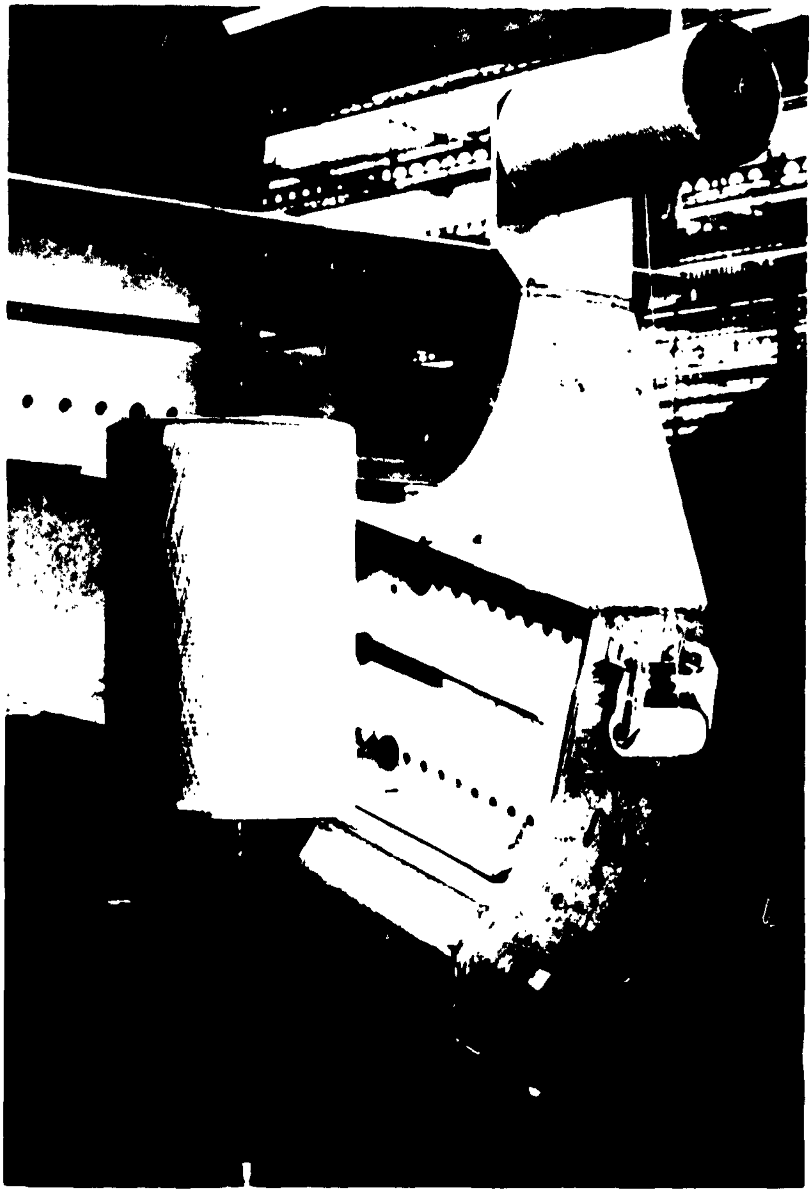


Figure 30. Sandwich-Wall Cylinder Shown in Rocketdyne Polar Winding Machine

Figure 31. Sandwich-Wall Cylinder Prior to Application of Core

2. Thermocouples were inserted between mid-layers of the built up end inserts during layup to record the laminate temperature during the cure cycle.

3. A layer of HT 432 adhesive film (0.005-inch gage) was applied over the area of the facing in contact with the core material. The film was chilled on a tray of dry ice to facilitate removal of the polyethylene separators.

4. The core segments were prefitted and prepared for bonding (see Figures 32 and 33). A Mannitol sugar filler was poured into the cells to prevent delamination of the core node bond and the free cells were compressed to the required detail dimensions. The filler was subsequently washed out with hot water and the segments fitted around a simple wood fixture. The segments were then degreased in a hot alkaline bath, rinsed in hot water, rinsed thoroughly in an acetone bath, dried in a 150° F oven and primed with Bloomingdale HT 424B primer, followed by a 30-minute air dry and 1-hour bake at 150 ±5° F.

5. The peripheral edges of the core segments were buttered with a thixotropic mixture of Bondmaster M611 adhesive, activated with CH-60 curing agent and combined with an equal amount (by weight) of 15-57A aluminum oxide powder. These edges were then positioned in the previously described subassembly. The core joints and abutments were filled with the same material.

6. An additional layer of HT 432 adhesive was applied over the core and an 0.008-inch circumferential winding was applied over the whole assembly. A longitudinal winding, at 16.5-degree orientation and an 0.016-inch thick circumferential winding, with No. 143 cloth laminates (26 ±2 percent resin content) interspersed, were applied in conformance with the governing drawing to produce doublers at each end of the cylinder.

7. The assembly was cured for one hour at 250° F followed by 2 hours at 350° F as shown by thermocouple trace.

8. Doubler stock was made for the inside ends of the cylinder by winding alternate layers of No. 143 "pre-preg" cloth and circumferential windings to the prescribed thickness. After completion of the conventional cure, the doubler stock was slit into 2-inch widths and cut to form a split hoop. The outer surface was sanded lightly to remove excess resin and/or blisters and cleaned with acetone in preparation for bonding.

9. After the cure and general cleanup of the sandwich cylinder, the inner surfaces of both ends of the cylinder were lightly sanded and washed with acetone in preparation for bonding. The doublers were positioned and trimmed to provide a maximum gap of 0.060 inches between the ends. An attempt was made to bond the doublers with a room-temperature-catalyst activated epoxy adhesive. The assembly proved too difficult to complete without excessive squeeze-out of the adhesive. Localized areas became adhesive-starved. The bond was finally accomplished on the first 2 subscale cases by use of locating pins in the doubler trim area and impregnating the activated adhesive into glass scrim cloth to simplify application.

10. The doublers were clamped in place till the adhesive set. The completed assemblies were then trimmed and prepared for testing. No inner skin delaminations occurred on the first 2 assemblies.

Sandwich-Wall Cylinder 3

Sandwich-wall cylinder 3 was fabricated in a manner similar to that described for the first 2 cylinders. A deviation was instituted to bond the inner end doublers, because the pot life of the diethylene-triamine (DETA) activated adhesive was very short and considerable difficulty was encountered in completing the assembly before the adhesive set up. An activator was substituted which required a 180° F cure. It was assumed that no degradation of the basic laminate would occur; however, after completion of the 1 hour cure at 180° F, serious delaminations appeared in the inner facings. One other change had been made in the fabrication procedure; namely, changing the core-to-face adhesive from 0.005-inch gage HT 432 to 0.010-inch gage HT 424. The cause of delamination was therefore considefed somewhat indeterminate.

Sandwich-Wall Cylinder 4

Sandwich-wall cylinder 4 was constructed in a manner identical to cylinder 3. However, both gages of adhesive were used in designated areas to determine if the change in adhesive might have caused the delaminations noted in cylinder 3. One additional innovation was introduced to preform the core segments. Santocel, a free silica material, was used as a thickening agent with water to fill the core cells in lieu of the Mannitol filler. The core segments were then frozen in a deepfreeze and the edges of the core were formed before the Santocel thawed out. This material was considerably easier to remove from the core cells and simplified the subsequent cleaning procedure.

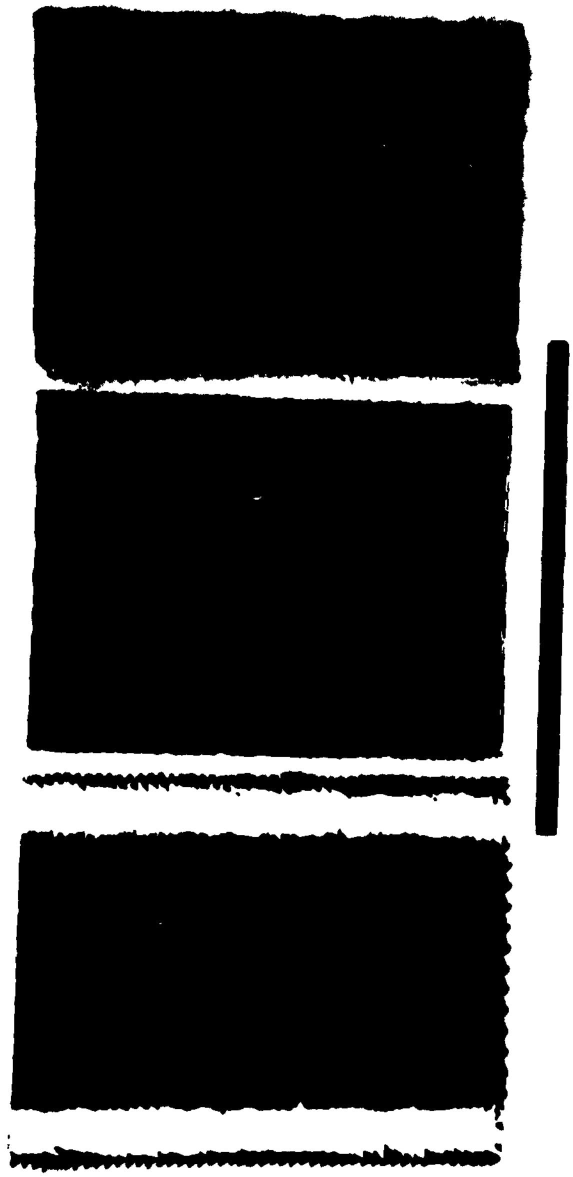


Figure 32. Multiwave Core Segments

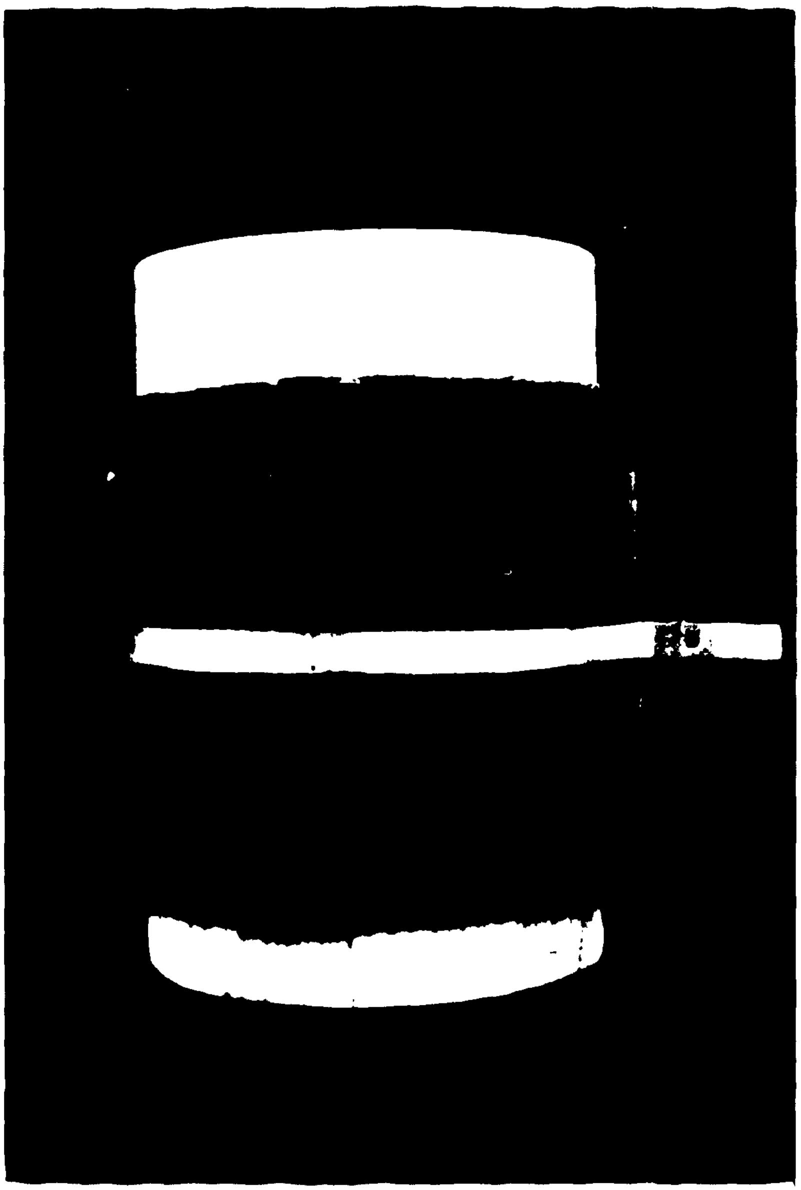


Figure 33. Prefitting of Multiwave Core Segments

The assembly proceeded satisfactorily but delaminations occurred again at the inner facing-to-core joint.

Sandwich-Wall Cylinders 5 and 6

Cylinders 5 and 6 were fabricated with procedures similar to those described for cylinder 4. However, 0.010-inch gage, HT 424 adhesive was used to bond both faces. Particular care was taken to maintain a close tolerance in thickness and to control each fabrication step. Some areas of delamination appeared on both specimens.

Sandwich-Wall Cylinder 7

It was decided to fabricate a seventh test specimen incorporating a higher resin content in the inner circumferential windings immediately adjacent to the adhesive bond line. This change was instituted because of the resin-depleted appearance of this interface, as indicated in a close examination of the previously-sectioned cylinder. A similar depletion was apparent in the sectioned portions of cylinders 5 and 6. The subject roving stock was obtained with a resin content of 24 ± 2 percent. All other roving stock was of 18 ± 3 percent resin content as originally specified, having been determined by numerous burst tests conducted under another study contract to produce optimum glass/resin ratios for burst applications. The 0.010-inch gage HT 424 adhesive was used for both facing-to-core bonds. No delaminations had occurred during the secondary bonding operation.

TOOLING FOR SUBSCALE CASES

In the interest of economy, it was necessary to use plaster mandrels in place of more elaborate and expensive metal break-away tooling which might produce superior parts. Additionally, plaster mandrels are being used by most filament-winding contractors for small- and intermediate-size monocoque, filament-wound pressure vessels. This concept was complicated by the necessity of using "washout" type mandrels in lieu of breakout plaster. The small access holes in the polar fittings made it impossible to get the necessary tools inside the subscale case to break out the plaster. Additional complications resulted when it became necessary to cure the rocket case in 2 stages instead of 1 as originally envisioned. These complications required that the fabrication portion of the contract be conducted as a development program with numerous revisions from subscale case to subscale case.

The details of the tooling studies in support of the subscale case fabrication were as follows:

Subscale Case 1

The mandrel for subscale case 1 was cast with Duplitool plaster, which is readily dissolved with hot water. This plaster was chosen because Rocketdyne had had considerable success with this material on their Army Ballistic Laboratory qualification tanks, and when producing a filament-wound model tank. All of these designs had been of monocoque construction and had been fabricated as single stage cures similar to those originally proposed for this application. The cost for the mandrel was less than $50, whereas collapsible metal tooling—if at all practical—was considerably greater.

After completion of the subscale case inner face wrapping, the skirt mandrel tooling must be positioned to lay up the sandwich skirts. Aluminum tooling was fabricated (see Figure E-5) consisting of welded sheet metal with angle reinforcements. Two problems proved to be critical: (a) matching the peripheral edges of the cylinder to the wound contour of the transition area, and (b) removing the tool from the inside of the skirt which had no open draft angle, without damaging the skirt or dome. The skirt tooling was originally of one piece construction and removal was to be performed pneumatically with externally applied air pressure, or with a bladder pressurized with water. The reaction was to be provided by the case dome backed up with the plaster mandrel.

When it proved difficult to remove the mandrel on subscale case 1, consideration was given to making a segmented metal tool. The proposed new designs appeared to be costly and there would have been considerable delay before a tool could have been available. It was therefore proposed to pour the skirt tooling with a castable washout material. The standard plaster materials could not be injected into the crevice between the skirt and dome intersection. Thus, it was proposed to use a Navmold formulation—a carbohydrate base material which may be removed by water or by melt out procedures.

Subscale Case 2

Before proceeding with subscale case 2, several studies were undertaken to evaluate the later approach to the skirt tooling. A simple sheet-metal cylinder was wrapped around the periphery of the subscale case, trimmed to a close fit, clamped tightly at the tangency point, and joined by riveting a doubler on the external surface. Several formulations of Navmold with variations of filler material were evaluated until one was found which would flow most readily into the small crevice and still not shrink excessively while setting up. After the Navmold hardened, the metal shroud was removed and the Navmold was smoothed; irregularities in the skirt tool to case joint were filled with conventional washout casting plaster.

Subscale Cases 3 and 4

Subscale cases 2, 3, and 4 used similar tooling approaches. The mandrel for subscale case 3 cracked (see Figure 34) after application and cure of inside facing. The cause of the cracking could not be readily ascertained, so an exact replacement was made.

Because of the apparent shrinkage of the subscale case mandrel during the first cure, some experiments were conducted in the use of a split mandrel and difficulty was encountered when trying to join the two clam shell segments. These experiments were conducted during a period when the mandrel vendor could not deliver Duplitool mandrels on the scheduled delivery dates. A mandrel was received before the Navmold mandrel bonding technique could be completed so fabrication was resumed with the previously described tooling.

Subscale cases 2 and 3 showed evidence of considerable shrinkage and local buckling of the inter facings of the skirts. However, when sectioned subsequent to completion of the static tests, areas of questionable integrity were noted on the inner facings of the subscale case itself which had not been detected through the small polar case openings. Subscale case 4 developed some small wrinkles in the inner circumferential windings of both subscale case and skirt areas. It was proposed to fabricate the fourth subscale case with the subscale case liner insulation applied to the mandrel, to evaluate the approach being considered for the full scale static firing and the structurally/thermally loaded test fullscale case. A McGregor proprietary insulation material (viz., R 122 Neoprene-type material) was used because presumably it could be molded directly on the mandrel and bonded to the subscale case during subsequent fabrication. After curing the liner, it was ascertained that the mandrel was cracked and could not be used for further fabrication. (It was assumed the mandrel had cracked due to excessive shrinkage of the liner material during its cure cycle.) Tests were therefore instituted to determine the creep characteristics of the mandrel materials. Two items became apparent: first, the Duplitool material could be used only for a one-stage cure, because it shrank excessively during the first cure. Since the first cure only partially advanced the resin system it was able to relieve itself during the second stage of the cure and without adequate support from the shrunken mandrel the circumferential windings buckled. Secondly, the Navmold (as modified for this application)–although having superior strength at room temperature–proved to have excessive creep under pressure at elevated temperature. Both materials were therefore ruled out for subsequent rocket case mandrel applications.

An extensive literature search was conducted to ascertain if other fabricators had encountered similar problems under conditions of two-stage curing. The most promising approach appears to be in the use of Kerr "DMM" plaster, which could conceivably be used for both the case and the skirt mandrels.

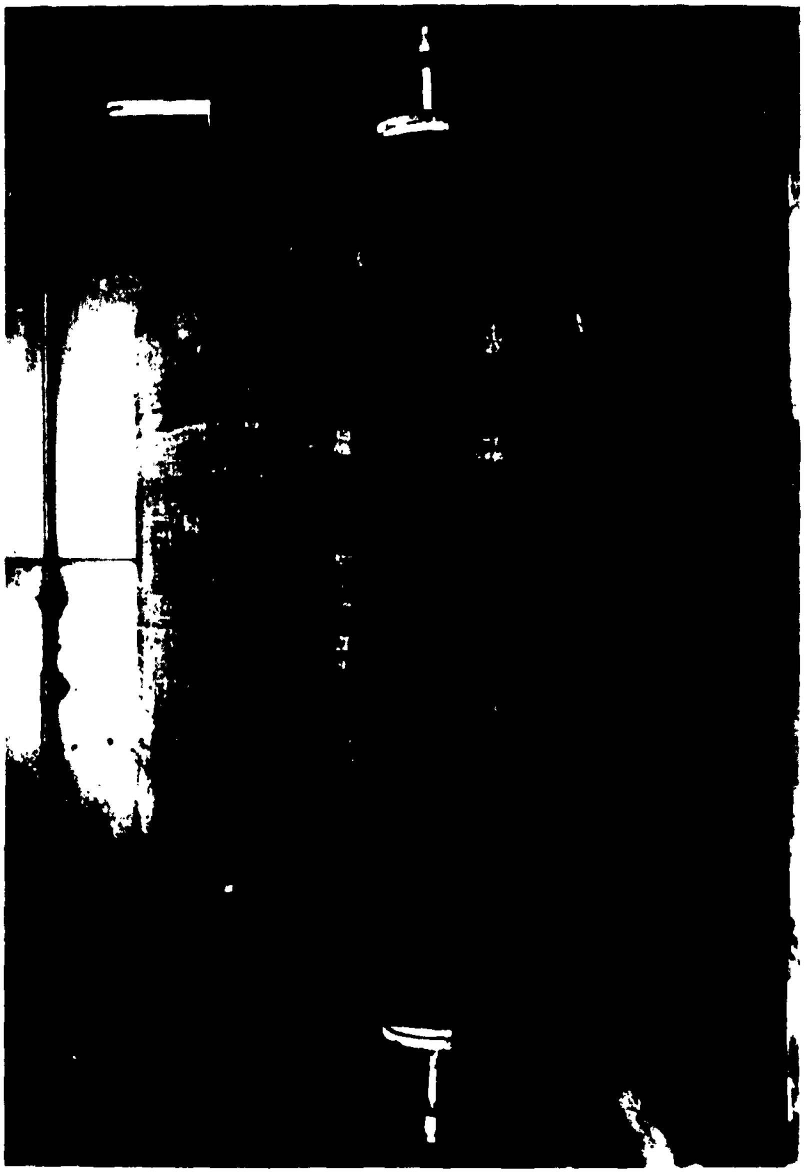


Figure 34. Rejected Subscale Case 3, Showing Crack In Mandrel

This material had been successfully employed by Aerojet-General on the Polaris design, using an integrally-bonded case liner. The case liner had been cured on the mandrel prior to application of the wet filament-wound material with no report of excessive shrinkage or deterioration of the mandrel. The material was soluble in a 15 percent solution of acetic acid; this material therefore was selected for subscale case 5.

Subscale Case 5

Due to excessive rain, the mandrel vendor facilities were incapacitated and the mandrels were fabricated at Rocketdyne with the split shell concept previously described. The two mandrel segments were successfully bonded with an epoxy adhesive formulation. The material was also used for the skirt tooling, but required extensive machining to fair it into the cylinder and prepare it for winding.

A long initial cure was applied to the subscale case to advance the cure prior to pouring the skirt mandrel. This change was instituted because there was evidence that the dome cure was being inhibited by the close encapsulation of the windings between the two plaster mandrels. The delaminations in the dome of subscale case 4 were also attributed in part to this restriction of cure.

After testing subscale case 5 it was ascertained that the windings resting on the two segments of the split core had been inhibited during their cure. One-half of the periphery was particularly affected. The circumferential windings had subsequently buckled, prior to testing, and the parting agent had migrated into the roving, possibly inhibiting the cure. It was assumed that this occurred because the mandrel had not been thoroughly dried out. The difference in moisture content was assumed to have caused the different reaction in the two halves.

Subscale Case 6

The mandrel for subscale case 6 was also fabricated with Kerr "DMM" plaster. Subsequent to application of the first windings, the first longitudinal wrap was inadvertently cut when trimming the dome reinforcement wrap. The mandrel was therefore stripped and required machining to repair damaged areas. It was subsequently sealed and used again.

It was decided to substitute a different material for the skirt mandrels on subscale case 6 because so much time had been required to fair the "DMM" material on subscale case 5 and an expensive machining operation had been required. Contacts with responsible engineers from Brunswick Corporation indicated that a sand/PVA mixture may be successfully used for mandrels subjected to several elevated temperature cures with minor creep. It had

been proposed to use the sand/PVA material for the subscale case mandrels. However, it is necessary to fill the mold and tamp the material to compact it since it cannot be poured or swept like plaster. This would have required new mandrel molds and caused considerable delay. For this reason, the DMM plaster was used for the subscale case mandrel and the sand/PVA mixture was used only for the skirts. The skirt mandrel material proved to be dimensionally stable and although fabrication problems were encountered on subscale case 6 they were not attributable to the shortcomings of the skirt mandrel.

FABRICATION PROCEDURES FOR SUBSCALE CASES

Six subscale sandwich rocket motor cases were fabricated by the Rocketdyne Division. The general configuration was established with two basic design considerations. First, the basic size of the pressure case was identical to the Army Ballistic Missile qualification case. This choice was made in the interest of using currently available tooling for the mandrels and winding machine adaptors. Secondly, the facing gages and core thicknesses were determined by manufacturing limitations and were, therefore, chosen to be identical to those proposed for the subscale rocket motor case. The first subscale case was fabricated in conformance with the procedure originally proposed. However, the problems encountered made it necessary to modify this procedure, and fabrication became a research development project.

The original approach and subsequent modifications of the fabrication procedures are herein described in detail.

Subscale Case 1

Subscale case 1 was fabricated as illustrated in Figure 35. The sequence of fabrication was:

Step 1. The aluminum polar head fittings were placed on the mandrel shaft, and the mandrel plaster was undercut sufficiently to fair in the exterior surface of the polar flange smoothly with the mandrel surface.

Step 2. The entire mandrel surface was inspected for irregularities and sanded smooth with number 150 grit sandpaper.

Step 3. The polar heads were then removed. Several coats of ZN 15 liquid surface sealer and parting agent were sprayed onto the mandrel, allowing a few minutes of air dry time between coats. After applying the final coat, the parting agent was air dried for one-half hour and then oven dried for one hour at 150° F. One coat of Plastilease 334 was applied on all mandrel surfaces, air dried, and then buffed lightly.

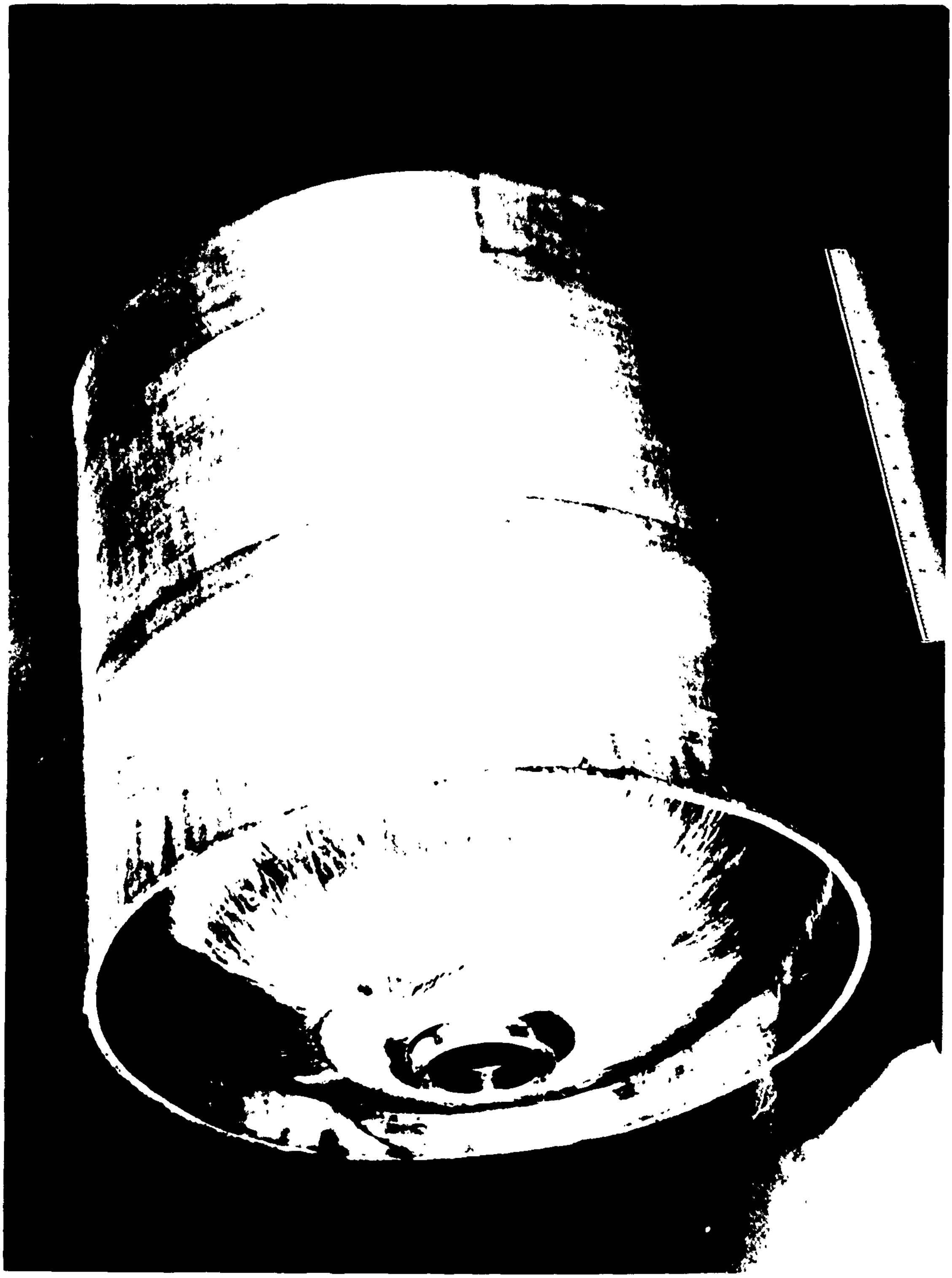


Figure 35. Subscale Case 1 After Fabrication

Step 4. The polar head fittings were vapor degreased and acid etched in a sulphuric acid-soldium dichromatic solution per the established NAA governing process specifications for bonding (MA0106-002).

Step 5. Exterior faying surfaces of the polar heads were sprayed with HT 424F primer and processed according to the NAA specification MA0106-002.

Step 6. HT 432 adhesive film was cut to dimension and placed on the polar head flanges.

Step 7. The polar heads were mounted on the mandrel and held in position with metal wedges.

Step 8. The mandrel was mounted in a horizontal filament winding machine and the first layer of 0.008 inch circumferential windings, under 18 pounds tension, was wrapped on the mandrel in one pass.

Step 9. The assembly was then placed in the Rocketdyne vertical winding machine (Figure 36) and the first layer (0.016 thick) of longitudinal roving was wound over the mandrel at a winding angle of 8° with a winding tension of 18 pounds.

Step 10. A one-half inch wide, 0.006 inch thick, stainless steel strip was wrapped around the mandrel and centered on the trim lines located 6.50 inches from the end of the skirts.

Step 11. Vinyl film (six mils thick) was installed in the cylindrical area of the mandrel between the stainless steel trim strips.

Step 12. The second longitudinal winding (0.026 inches thick) was then wrapped on with the winding angle set at 10° and with a winding tension of 18 pounds.

Step 13. Mylar tape was applied, on both ends of the mandrel, around the tangency points and to a point approximately one inch upon the domes, covering the areas where the aluminum skirt tooling contacted the dome windings.

Step 14. Two, single-piece aluminum end skirt mandrels, coated with Plastilease 334 parting agent, were located on the shaft and secured in position against the windings on each dome. The wooden outer dome tooling was then forced on over the aluminum skirt tools.

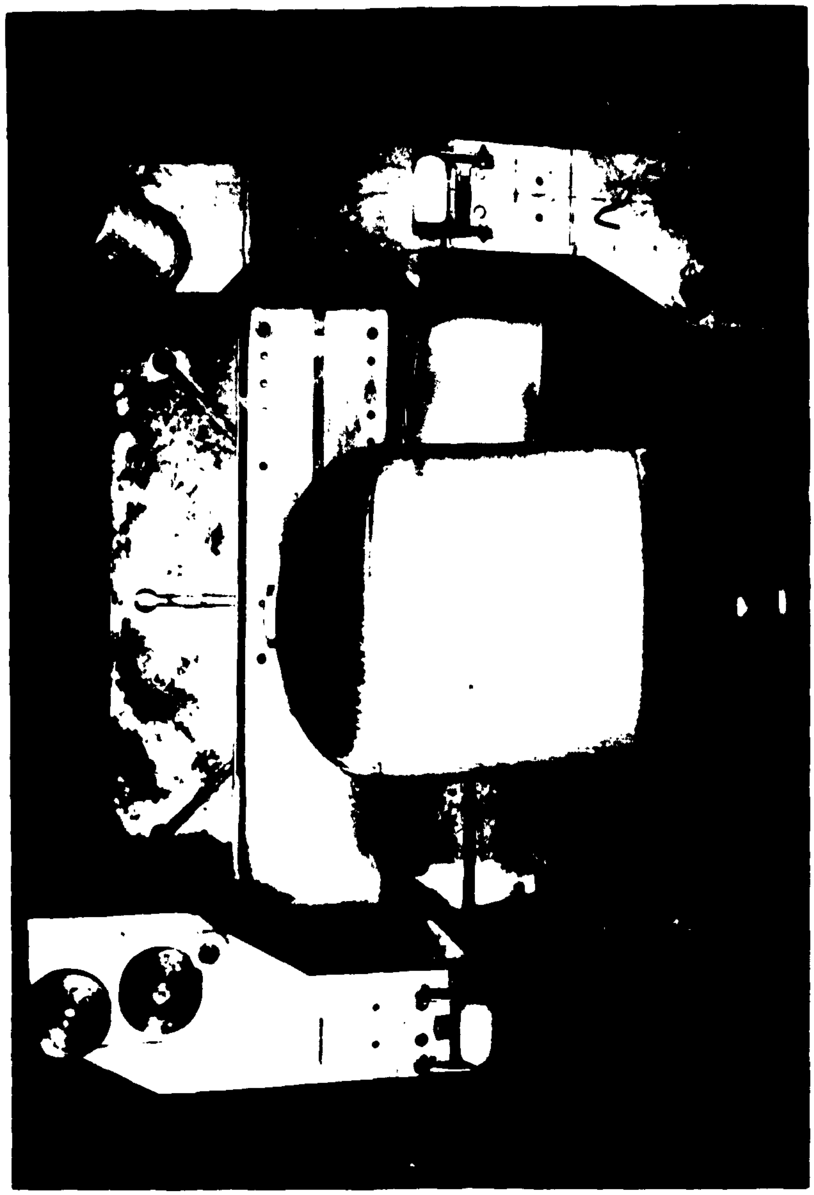


Figure 36. Subscale Case 1 in Polar Winding Machine

Step 15. The case, with attached tooling, was mounted in the horizontal winding machine and the area between the end of the aluminum skirt tooling and the tangency point was faired in with loosely wrapped dry glass roving.

Step 16. One 0.008 inch thick layer of circumferential winding, under 18 pounds tension, was wrapped from 0.75 inch beyond the skirt trim line to the 6.50 inch station where the stainless steel trim strips were located. A similar circumferential winding was added in the same manner to the opposite end of the subscale case.

Step 17. The exposed 0.026 inch thick longitudinal windings were cut at the 6.5-inch stations on both ends, and the loose windings, vinyl films, and stainless steel protective trim strips were removed.

Step 18. A circumferential winding (0.008 inch thick) was applied, under 18 pounds of tension, in the cylindrical area of the case between the 6.50 inch trim stations.

Step 19. Three layers of preimpregnated unidirectional number 143 cloth were cut to the dimensions in the drawing and applied over the 0.008 inch thick circumferential windings in the positions indicated in Figure E-1. The warp of the number 143 cloth was positioned to run parallel with the axis of the mandrel. A similar number and type of preimpregnated number 143 cloth laminations were applied to the opposite end of the mandrel. All longitudinal joints were of the butt type, and the butt joint of each succeeding lamination was staggered.

Step 20. One layer of 0.008-inch circumferential windings, under 18 pounds of tension, was wrapped across the entire case from the right end, skirt trim line to the left end, skirt trim line.

Step 21. Six stainless steel strips were positioned evenly around the circumference of the case between stations 5.50 and 6.50 on each end of the case in the areas where core spacers were to be applied.

Step 22. Three equally-spaced circumferential shim windings were wrapped between 5.50-inch and 6.50-inch stations on both ends with a minimum of tension. Each of these wraps was formed by superimposing layers of the standard 0.1-inch wide roving. Three to four layers were applied depending upon the amount of spacing required, as determined by a straight edge placed on the skirt circumferential winding and parallel with the axis of the mandrel. These windings were cut in the areas above the six stainless steel strips which were subsequently removed.

Step 23. HT 432 adhesive film was applied to the cylindrical portion of the tank between the 6. 50-inch stations. The adhesive was butted and not allowed to overlap in the longitudinal joint.

Step 24. All six honeycomb core segments were cut 3/8-inch oversized and the core was crushed back 3/16-inch on all edges in a manner commensurate with that used to form the small sandwich cylinder core segments. The joints were approximately as shown in Figure 37.

Step 25. Each piece of cut core was cleaned and primed with HT 424F primer in accordance with NAA specification MA0106-002.

Step 26. HT 424 foam 0. 1-inch thick was taken from cold storage, allowed to warm to room temperature, and then cut to the trimmed dimensions of the skirt cores.

Step 27. The separator was removed from the foam, and one piece of foam was properly positioned on the inner surface of each of the end skirt core segments.

Step 28. Working with one piece of core and foam at a time, the foam and core were placed in a 130° F oven for approximately one minute. When soft, the foam was quickly worked fully down into the core. The foam-filled core was removed from the oven and allowed to cool to room temperature.

Step 29. A 0. 5-inch wide piece of HT 424 foam was forced into the 0. 25-inch section of core in the areas specified in the drawing in the manner described in step 28.

Step 30. The 2 prepared center section cores (0. 25-inch thick) were positioned on the mandrel; a 1/16-inch thick piece of HT 424 foam was added to the longitudinal butt splice joints, then held in against the mandrel with loosely wound glass roving.

Step 31. The four 0. 18-inch thick end skirt cores filled with foam were then positioned on each side of the center core sections with a 1/16-inch thick strip of HT 424 foam placed between all butting surfaces. A hair dryer-type heat gun was utilized from time to time to soften the butt joint foam and permit close honeycomb contact at the butt joints (Figure 37). Loosely wound glass roving was again used to hold the various core segments in place.

Step 32. HT 432 adhesive film, cut 1-inch undersize in the width dimension, was applied to the outer surface of the center core segments, and one layer of 0. 008-inch thick circumferential windings, under 18 pounds of tension, were applied over the adhesive. The dry glass roving on each end of the center core sections was then removed.

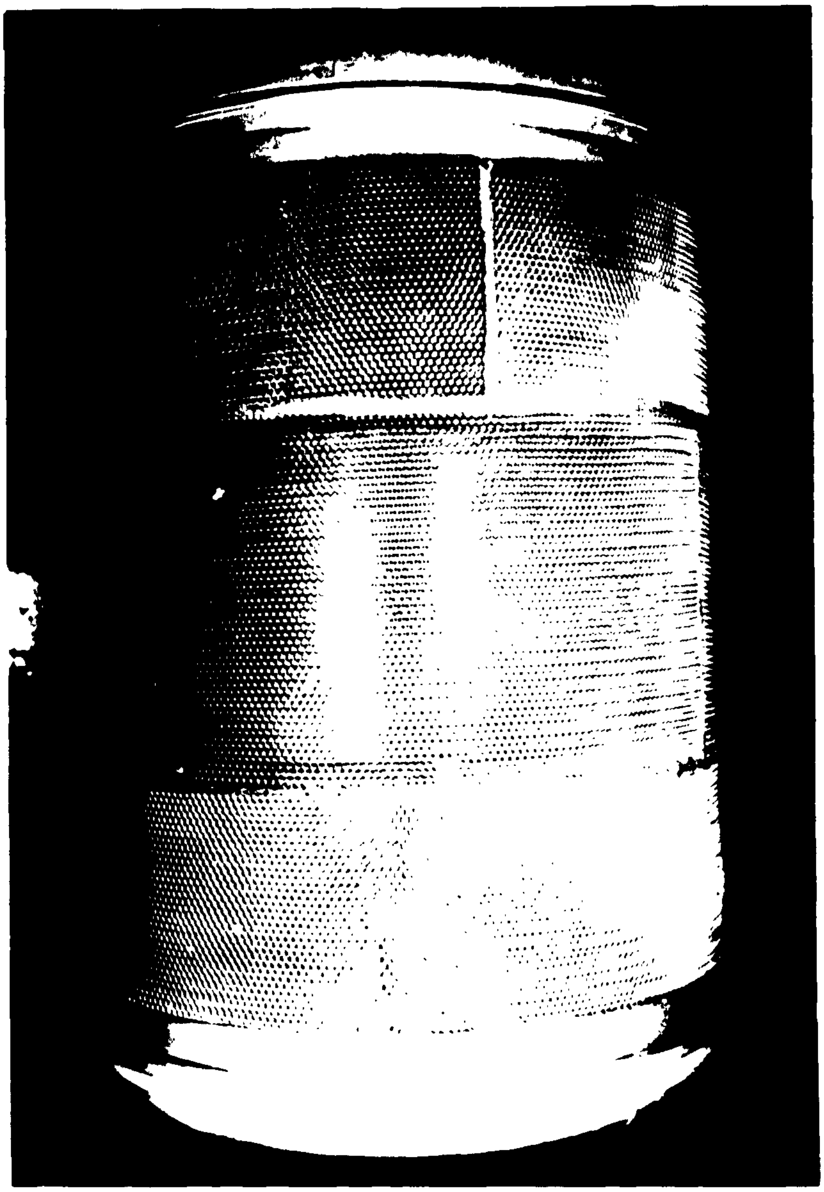


Figure 37. Honeycomb Core Wrapped Over Inner Skin

33. HT 432 adhesive film was cut and positioned over the remaining exposed center core and end skirt case segments.

34. The remainder of the first circumferential windings of the outer face was wound over the HT 432 adhesive on each of the end skirts and unwrapped section of the center core segments. The direction in which the winding machine traveled when applying these windings was always from the end of the skirt towards the point where these skirt windings butted the previously wound center windings.

35. At this point, the mandrel with windings and core was mounted in the vertical polar winding machine, and 1 cycle of 0.016-inch longitudinal wraps was wound on with an angle of 8 degrees and roving under 18 pounds of tension.

36. The mandrel and partially wound case was then mounted in the horizontal machine. Two plies of No. 143 preimpregnated glass cloth were applied to each end of the mandrel with the individual layers trimmed to the dimension on Figure E-1. The warp of the cloth was oriented in the longitudinal direction of the subscale case.

37. Two layers of 0.008-inch thick circumferential windings, under 18 pounds of tension, were wound over the entire length of the case, and the excess longitudinal dome windings were removed to the end skirt trim line.

38. The entire assembly was then mounted vertically in a curing fixture and cured in an oven with the following temperature cycle:

a. 1 hour - 180° F.
b. 1 hour - 250° F.
c. 2 hours - 350° F.

The cure cycle was monitored with a thermocouple attached to the outer surfaces of the subscale case.

39. Both end skirt fittings were removed with the aid of hydraulic pressure, and the plaster mandrels were washed out.

40. The case was then trimmed of excess material.

When one of the skirt tools could not be removed by the method stated above, it became necessary to trim the skirt from the case. The completed case is shown in Figure 35.

Several changes were instituted on the fabrication sequence for the second subscale case because of difficulties encountered when building subscale case 1.

The aluminum skirt tooling proved difficult to remove; therefore, plaster was cast on the domes as described in the tooling report.

Because the plaster might restrict the cure of the inner winding, it was decided to fabricate subscale case 2 and subsequent subscale cases with a two-stage cure.

Bloomingdale's FM 97 adhesive was added, between the core and circumferential winding on the inner face in lieu of depending on the HT 424 foam to form a primary bond, from 6. 50-inch station outward on each of the skirts.

Difficulty had been encountered in cutting the circumferential wraps which acted as shims to locate the thin core segments. Nylon roving, impregnated with U.S. Polymeric E787, was used to fill the variable void area and support the core. The lower modulus of the nylon prevented these continuous circumferential windings from additing additional restraint at the skirt to dome attachment and inducing additional stresses in the dome winding.

Subscale Case 2

The second filament wound sandwich rocket case was fabricated using the same materials and assembly procedure as those used on subscale case 1 with the following deviations:

Steps 1 through 12 same as subscale case 1.

Steps 13 through 18 modified as follows:

1. The partially wound mandrel was placed in the Rocketdyne horizontal winding machine and an 0. 008-inch thick circumferential winding was wrapped on both ends of the casefrom the tangency point to the 6. 50-inch station.

2. The exposed 0. 026-inch thick longitudinal windings were cut at the 6. 50-inch stations on both ends and the loose windings, vinyl film and stainless steel protective trim strips were removed.

3. Circumferential wraps, 0. 008-inch thick, were then added to the cylindrical area of the subscale case between the 6. 50-inch stations.

4. The cylindrical portion of the subscale case was wrapped with dry No. 181 glass cloth, taped in place, the entire assembly was cured to the following schedule:

a. 1 hour - 180° F.

b. 2 hours - 250° F.

5. After the above cure, and removal of the No. 181 strip cloth, the sheet metal and skirt mold tooling was attached to the subscale case, and the Mannitol plaster for the end skirts was poured into the mold. After drying,

the mold was removed and attached to the opposite end of the subscale case, and a similar procedure was followed to mold the other end skirt.

6. The subscale case with the end skirt molding (Figure 38) was mounted in the horizontal or circumferential winding machine, and plaster was swept into voids between the dome tangent line and the edge of the skirt mandrel plaster, and on the surface of the skirt mandrel. Sandpaper (No. 150 grit) was used to smooth the mandrel surface where required.

7. A chromel-alumel thermocouple was inserted in the plaster at the dome tangency point, and a longitudinal groove was made in the skirt plaster so that the thermocouple lead would lay flush with the mandrel surface.

8. Several coats of Plastilease 334 parting agent were liberally applied to the plaster skirt mandrels and buffed when dried. Masking tape was wrapped on the windings near the tangency points to prevent coating these windings with parting agent. The tape was removed prior to the next operation.

9. Circumferential wraps, 0.008-inch thick, were wound on both ends starting at a point 0.25-inch beyond the skirt trim line and ending at the tangency line where these windings butted the partially cured circumferential windings.

Steps 19 and 20 same as subscale case 1.

Steps 21 and 22 were modified as follows:

1. A coat of U.S. Polymeric E787 formulation epoxy resin (similar to that resin used to impregnate the glass roving) was applied with a brush to both ends of the subscale case between 5.50-inch and 6.50-inch stations.

2. This area was then filled with nylon roving to the requirement of Figure E-1. Additional U.S. Polymeric E787 resin with Santocel added was applied between layers of the domes adjacent to the polar fillings.

Steps 23 through 30 same as subscale case 1.

The following steps were added between steps 30 and 31.

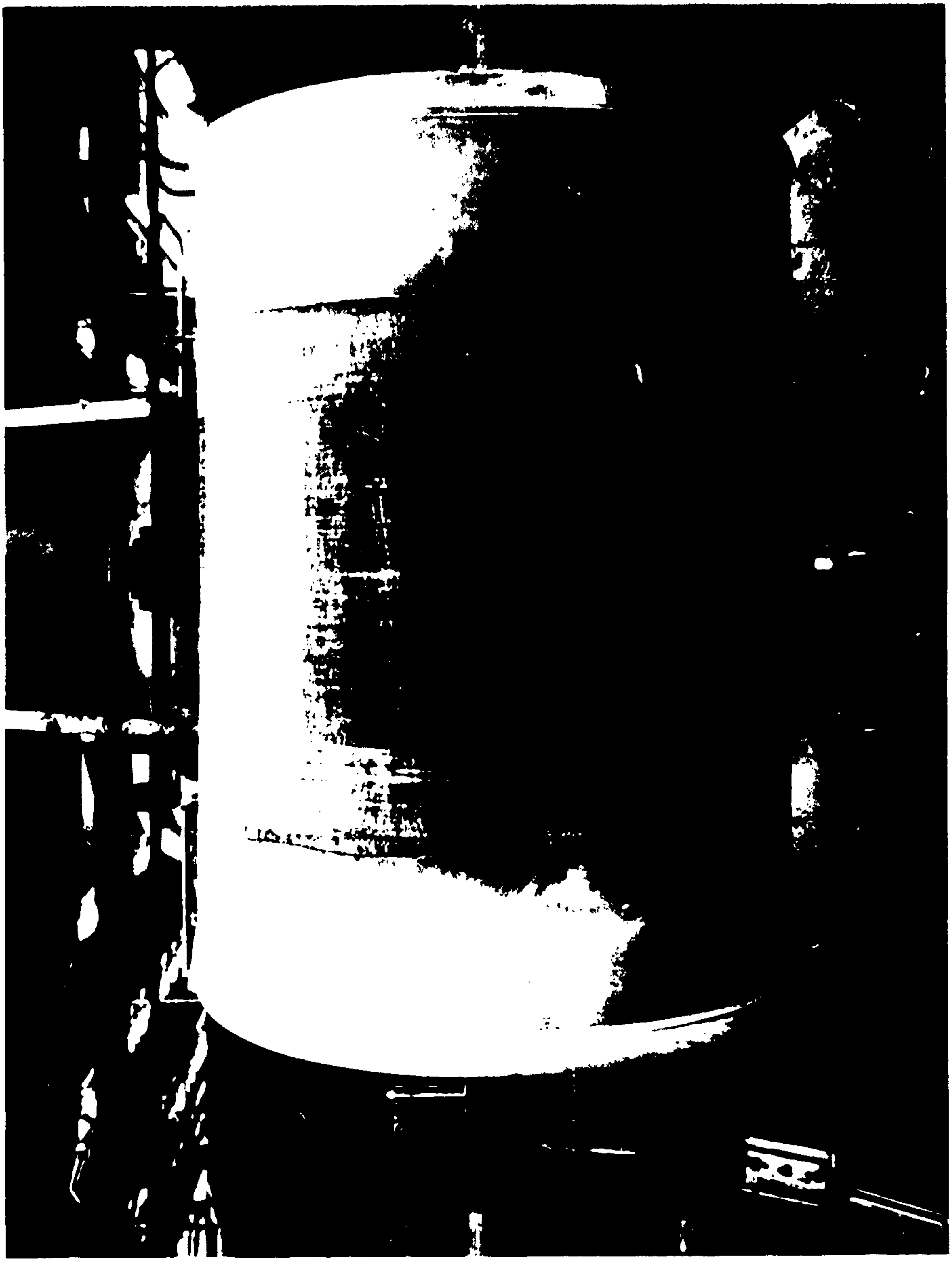
A piece of FM-97 adhesive was cut and applied to both ends of the subscale case to cover the area from 6.50-inch station to 0.5-inch beyond the end skirt trim line.

Step 31 same as subscale case 1.

The following steps were added between steps 31 and 32.

The six segmented aluminum rings (three for each end) were degreased, etched, and primed with HT 424F primer per NAA specification MA0106-002. They were positioned (see Figure XX) so that the three resulting gaps were approximately equal. These gaps were filled with a thixotropic epoxy formulation.

Steps 32 through 37 same as subscale case 1.



Steps 38 through 40 were modified as follows:

1. The entire assembly was then mounted vertically in a fixture and cured to the following schedule.

   a. 1 hour - 180° F.
   b. 1 hour - 250° F.
   c. 3 hours - 300° F.

2. The end skirt and main case mandrel were removed with water.
3. The subscale case was subsequently trimmed of excess materials, and the end skirts were machined.

There was evidence that the secondary dome winding had slipped during cure causing wrinkles in the dome. This slippage or springback was assumed to have occured because the small area of circumferential windings, applied to the dome during the first stage layup, was insufficient to hold the winding tension when the cylindrical portion of the secondary winding was removed. The softened resin acted as a lubricant. It was decided, therefore, to reduce the tension on the secondary winding of the subscale case 3 dome.

It proved difficult to trim the secondary polar winding of the dome to the stepped dimensions specified in Figure E-1. Thus, a total step of 0.026 inches was produced which was considered to be a serious stress riser. Therefore, it was proposed to apply the secondary reinforcement in two stages of 0.016 inches each, trimming each stage separately.

Subsequent to testing the second subscale case, it was sectioned and breaks in the internal circumferential windings were noted (Figure 39).

Subscale Case 3

Subscale case 3 was fabricated in basic conformance with Figure E-1. The deviations noted above were incorporated by the following fabrication procedure.

1. The aluminum polar head fittings were placed on the mandrel shaft. The mandrel plaster was undercut sufficiently to fair the exterior surface of the polar flange smoothly with the mandrel surface.

2. The entire mandrel surface was inspected for irregularities and sanded smooth with No. 150 grit sandpaper.

3. The polar heads were then removed and several coats of ZN-15 liquid surface sealer and parting agent were sprayed onto the mandrel allowing a few minutes of air dry time between coats. After applying the final coat, the parting agent was air dried for one hour and then oven dried

for one hour at 150° F. One coat of Plastilease 334 was applied on all mandrel surfaces, air dried, and then buffed lightly.

4. The polar head fittings were vapor degreased and acid etched in a sulphuric acid sodium dichromate solution per the established NAA governing process specifications for bonding (MA0106-002).

5. Exterior faying surfaces of the polar heads were sprayed with HT 424F primer and processed according to the NAA Specification, MA0106-002.

6. HT 432 adhesive film was cut to the dimensions of, and placed on, the polar head flanges.

7. The polar heads were mounted on the mandrel and held in position with metal wedges.

8. The mandrel was mounted in a horizontal filament winding machine, and the first layer of 0.008 inch circumferential windings, under 18 pounds of tension, was wrapped on the mandrel in one pass.

9. The assembly was then placed in the Rocketdyne vertical winding machine, (Figure 36) and the first layer (0.016-inch thick) of roving under 18 pounds of tension was wound longitudinally over the mandrel at a winding angle of 8 degrees.

10. A 0.5-inch wide, 0.006-inch thick, stainless steel strip was wrapped around the mandrel and centered on the trim lines located at the 6.50-inch stations.

11. Vinyl film (6 mils thick) was installed in the cylindrical area of the mandrel between the stainless steel trim strips.

12. The second longitudinal winding (0.016-inch thick) was then wrapped on the mandrel under 10 pounds of tension and with the winding angle set at 9 degrees.

13. A second set of 0.5-inch wide, 0.006-inch thick, stainless steel strip was wrapped on over the first longitudinal winding at the 6.00-inch stations.

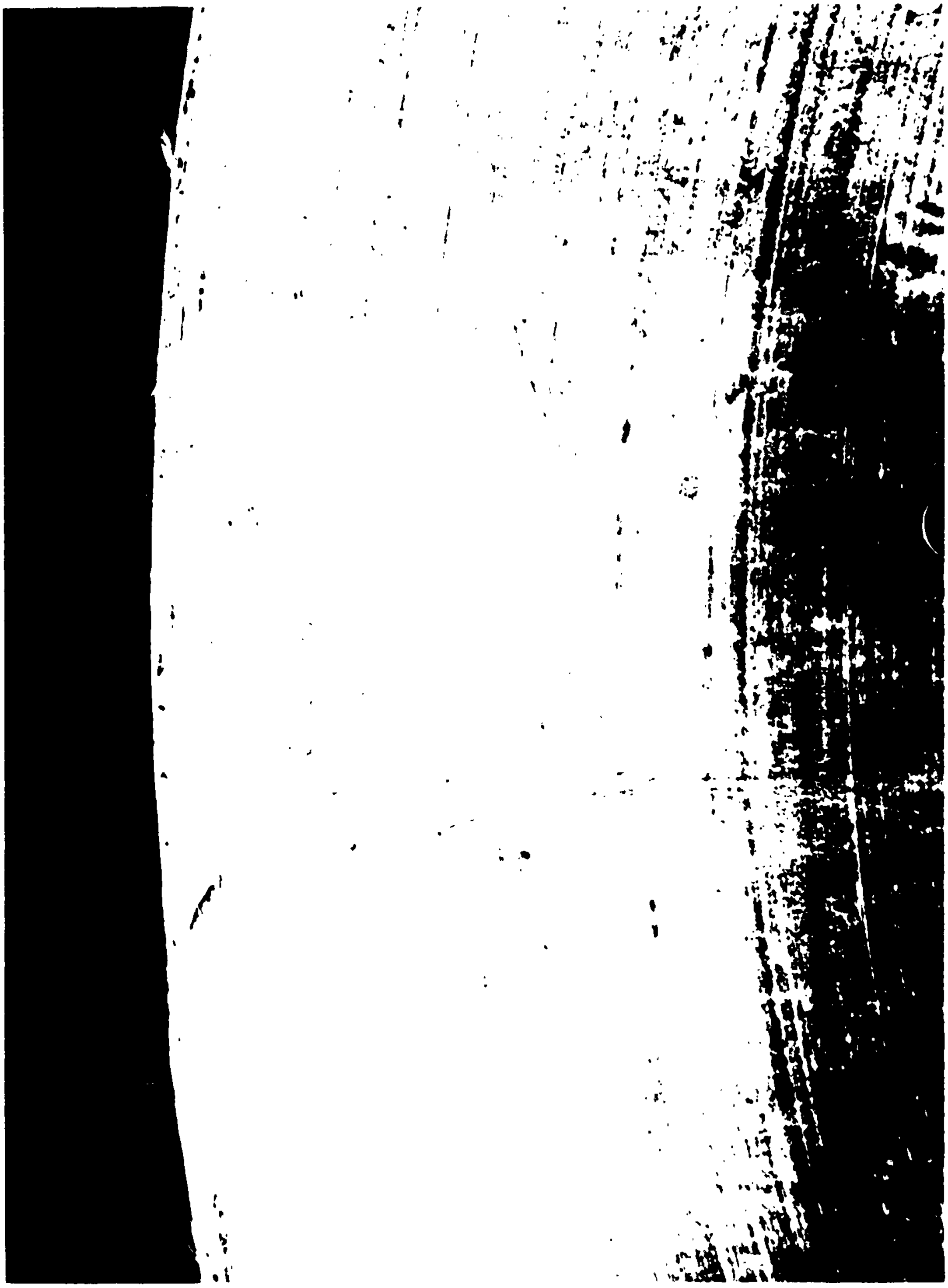


Figure 31. Wrinkles in Subscale Case 2

14. The third longitudinal winding (0.016-inch thick) was wrapped on the mandrel under 10 pounds of tension and with the winding angle set at 10 degrees.

15. The case was mounted in the horizontal winding machine, and 0.008-inch thick circumferential windings, under 15 pounds of tension, were wrapped on from the tangency points to the 6.00-inch station.

16. The second and third layers of longitudinal windings, applied in steps 14 and 13, were cut at the 6.50-inch station on both ends and the base windings, vinyl film, and stainless steel trim strips at the 6.50-inch stations were removed.

17. The third layer of longitudinal windings were subsequently trimmed at the 6.00-inch stations and the loose windings and stainless steel trim strips were removed.

18. Circumferential wraps, 0.008-inch thick and under 15 pounds of tension, were added to the cylindrical area of the case between the 6.00-inch stations.

19. The cylindrical portion of the case was wrapped with dry No. 181 glass cloth and taped in place and the entire assembly was cured to the following schedule:

a. 1 hour - 180° F.
b. 2 hours - 250° F.

20. After the above cure and removal of the protective No. 181 strip cloth, the sheet-metal skirt mold tooling was attached to the subscale case and the Navmold plaster for the end skirts was poured into the mold. After drying, the mold was removed and attached to the opposite end of the subscale case, and a similar procedure was followed to mold the other end skirt.

21. The subscale case with the molded end skirts was mounted in the horizontal or circumferential winding machine (Figure 38) and plaster was swept into any voids between the dome tangent line and the edge of the skirt mandrel plaster, and on the surface of the skirt mandrel. Sandpaper, No. 150 grit, was used to smooth the mandrel surface and fair in areas where required.

22. A chromel-alumel thermocouple was inserted in the plaster at the dome tangency point and a longitudinal groove was made in the skirt plaster so that the thermocouple lead would lay flush with the mandrel surface.

23. Several coats of Plastilease 334 parting agent were liberally applied to plaster skirt mandrels and buffed when dried. Masking tape was wrapped on the windings near the tangency points to prevent coating these windings with parting agent. The tape was removed prior to the next operation.

24. Circumferential wraps, 0.008-inch thick, were wound (15 pounds of tension) on both ends starting at a point 0.25 inch beyond the skirt trim line and ending at the tangency line where these windings butted the partially cured circumferential windings.

25. Three layers of preimpregnated unidirectional No. 143 cloth were cut to the dimensions in the drawing and applied over the 0.008-inch circumferential windings in the positions indicated in Figure E-1. The warp of the No. 143 cloth was parallel with the axis of the mandrel. A similar number and type of preimpregnated No. 143 cloth laminations were applied to the opposite end of the mandrel. In all instances, the joints were of the butt type and staggered.

26. One layer of 0.008-inch circumferential windings were wrapped across the entire subscale case from 0.25-inch outside the right end skirt trim line to 0.25-inch outside the left end skirt trim line.

27. A coat of U.S. Polymeric E787 epoxy resin (similar to the resin used to impregnate the glass roving) was applied with a brush to both ends of the subscale case between 5.50-inch and 6.50-inch stations.

28. This area was then filled with nylon roving under 4 pounds of tension to meet the requirement of Figure E-1). Additional U.S. Polymeric E787 adhesive was applied between each layer (Figure 40).

29. HT 432 adhesive film was applied to the cylindrical portion of the tank between the 6.50-inch stations. The adhesive was butted and not allowed to overlap in the longitudinal joint.

30. All six honeycomb core segments were cut 3/8 inch oversized and the edge of the core was crushed back 3/16 inch on all edges in a manner commensurate with that used to form the small sandwich cylinder core segments. The joints were approximately as shown in Figure 37.

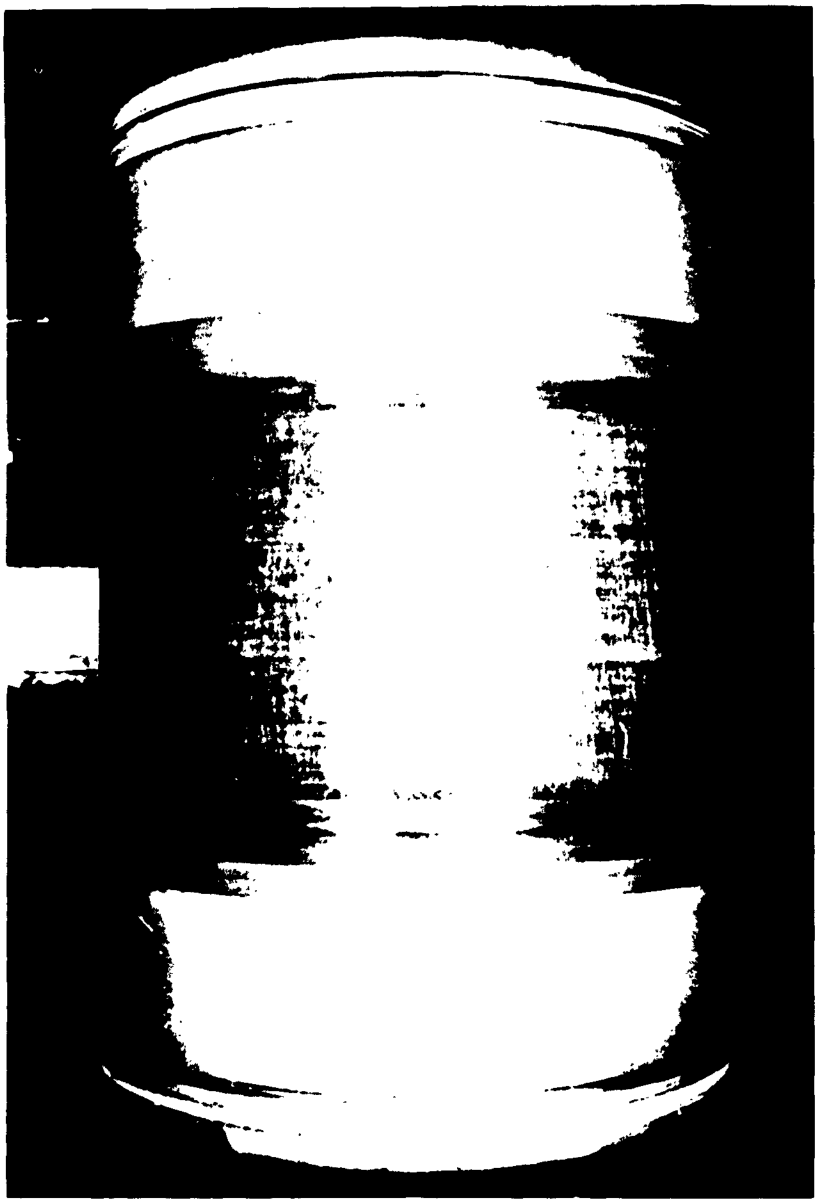


Figure 40. Nylon Roving on a Subscale Case

31. Each piece of cut core was cleaned and primed with HT 424F primer in accordance with NAA Specification MAB0106-002.

32. HT 424 foam, 0.1-inch thick, was taken from cold storage, allowed to warm to room temperature, and then cut to the trimmed dimensions of the four end skirt cores.

33. The separator was removed from the foam and one piece was properly positioned on inner surface of each of the end skirt core segments.

34. Each piece of core and foam was placed in a 130° F. oven for approximately one minute. When soft, the foam was quickly worked fully down into the core. The foam filled core was removed from the oven and allowed to cool to room temperature.

35. A 0.5-inch wide piece of HT 424 foam was forced into the 0.25-inch section of core in the areas specified in the drawing in the manner described in step 28.

36. The two prepared 0.25-inch thick center section cores were positioned on the mandrel. A 1/16-inch thick piece of HT 424 foam was added to the longitudinal butt splice joints and held against the mandrel with loosely wound glass roving.

37. A piece of FM-97 adhesive was cut and applied to both ends of the subscale case to cover the area from 6.50-inch station to 0.5-inch beyond the end skirt trim line.

38. The four 0.18-inch thick end skirt cores, filled with foam, were then positioned on each side of the center core sections with a 1/16-inch thick strip of HT 424 foam placed between all butting surfaces. A hair dryer-type heat gun was utilized from time to time to soften the butt joint foam and permit close honeycomb contact at the butt joints.

39. HT 432 adhesive film, cut 1-inch undersized in the width dimensions, was applied to the outer surface of the center core segments. One layer of 0.008-inch thick circumferential wraps (18 pounds of tension) was wound over the adhesive. The dry glass roving on each end of the center core section was then removed.

40. HT 432 adhesive film was cut and positioned over the remaining exposed center core and end skirt core segments.

41. The remainder of the first circumferential windings of the outer face was wound (18 pounds of tension) over the HT 432 adhesive on each of the end skirts and the unwrapped section of the center core segments. The direction of the winding machine travel, when applying these windings, was

always from the ends of the skirts toward the point where these skirt windings butted the previously wound center windings.

42. At this point, the mandrel with windings and core was mounted in the vertical polar winding machine and one cycle of 0.016-inch longitudinal wraps was wound on with an angle of 8 degrees and under 12 pounds of winding tension.

43. The mandrel and partially wound subscale case was then mounted in the horizontal machine and two plies of No. 143 preimpregnated glass cloth applied to each end of the mandrel with the individual layers trimmed to the dimension of Figure E-1.

44. Two layers of 0.008-inch thick circumferential winding were wound (18 pounds of tension) over the entire length of the subscale case and excess longitudinal dome windings were removed to the end skirt trim line.

45. The entire assembly was then mounted vertically in a curing fixture and cured to the following schedule:

a. 1 hour - 180° F.
b. 1 hour - 250° F.
c. 3 hours - 300°F.

The above temperatures were monitored with the thermocouple inserts inside the subscale case at the tangency point.

46. The end skirt plaster and mandrel plaster were removed with water.

47. The subscale case was subsequently trimmed of excess materials.

Subsequent to curing several areas of delamination (Figure 41) were noted in the skirts of subscale case 3. Examination of the inner surface of the cylindrical portion of the tank revealed numerous erratic checks. Close examination was impossible because of the small polar openings but the checks did not appear to be deep or to have ruptured the internal windings. The subscale case was therefore designated for burst testing.

Some slippage of the secondary dome wraps was noticed.

The subscale case was sectioned after testing. There was some uncertainty with respect to the progression of failure and of the completeness of the cure of the dome. Therefore the cure cycles were modified.

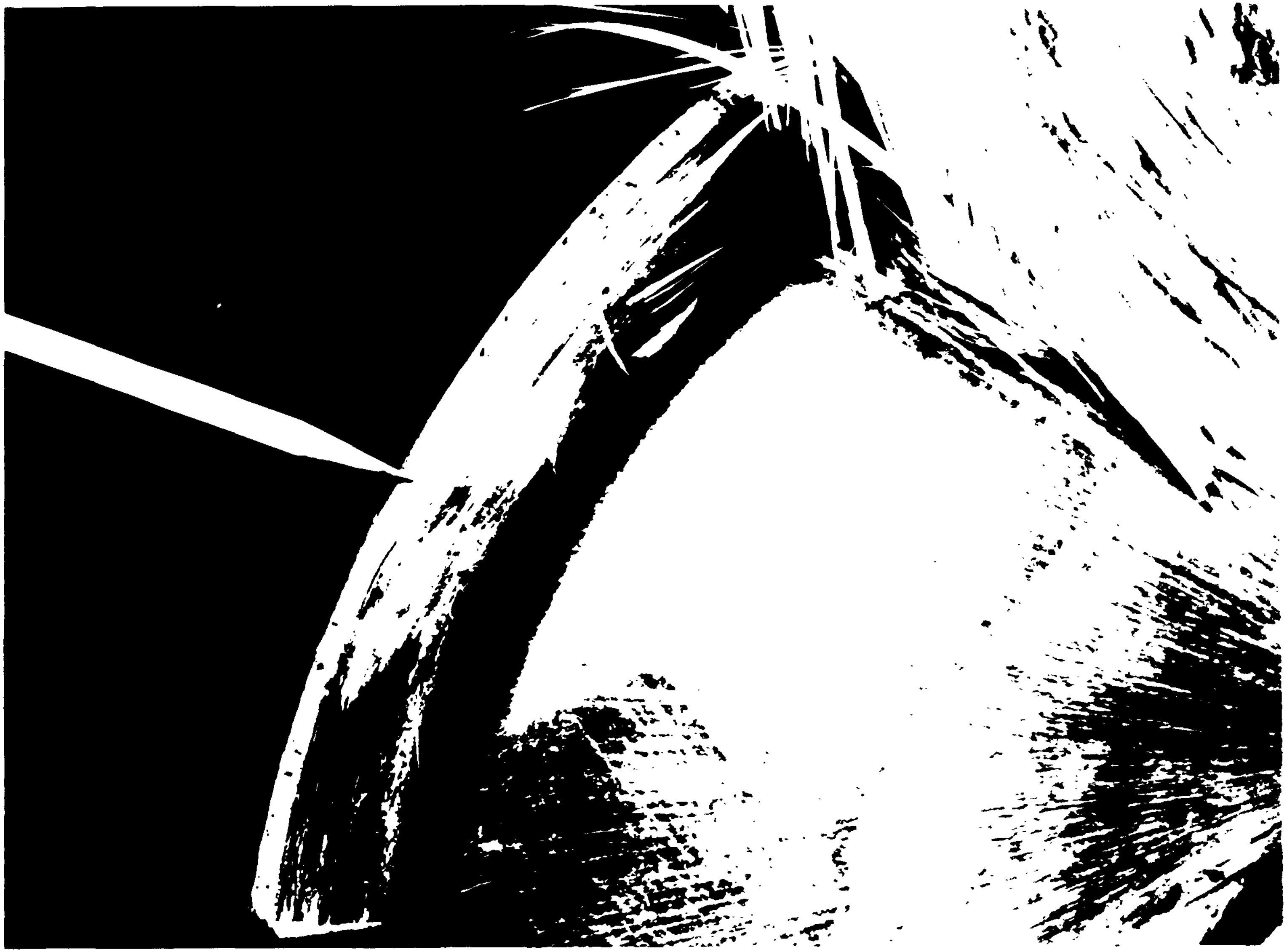


Figure 41. Subscale Case Delamination in Skirt

Subscale Case 4

No. 4 filament-wound sandwich rocket case was fabricated using the same materials and assembly procedures as those used on subscale case 3 with the following deviations:

Steps 1 through 18 were the same as for subscale case 3.

Step 19 was modified as follows:
The cylindrical portion of the case was wrapped with dry No. 181 glass cloth and taped in place and the entire assembly oven cured to the following schedule:

a. 2 hours - 250° F.
b. 1 hour - 275° F.

Steps 20 through 44 were the same as for subscale case 3.

Step 45 was modified as follows:
The entire assembly was mounted vertically in a curing fixture and cured to the following schedule:

a. 1 hour - 250° F.
b. 3 hours - 275° F.

The assembly was rotated to a horizontal position in the oven after the 3 hours at 275° F, and the cure was completed after 2 hours at 350° F.

Steps 46 and 47 were the same as for subscale case 3.

The quality of the fourth subscale case was very questionable. Figures 42 and 43 show the areas in the skirt and inner cylinder walls that had wrinkled and creased. The cause of these was uncertain. In the interest of building a case that would carry the design burst pressure and because of the current inability of the stress to be transferred proportionally to the longitudinal windings in the sandwich outer facing it was decided to increase the gage of the sandwich inner face windings on subscale case 5.

The primer system and the adhesive that attaches the polar fittings to the dome windings was changed from the HT 424 system to one incorporating Bondmaster M602C primer and FM97 adhesive.

There were also changes in the mandrels for the skirt and the subscale case. These are discussed in the section of this report describing the tooling studies.

Figure 15. Skirt of Subscale Case 4

Subscale Case 5

Subscale case 5 was fabricated as illustrated in Figure E-2, in the following steps:

1. The aluminum polar head fittings were placed on the mandrel shaft. The mandrel plaster was undercut sufficiently to fair in the exterior surface of the polar flange smoothly with the mandrel surface.

2. The entire mandrel surface was inspected for irregularities and sanded smooth with No. 150 grit sandpaper.

3. The polar heads were then removed and several coats of ZN 15 liquid surface sealer and parting agent were sprayed into the mandrel allowing a few minutes of air dry time in between coats. After applying the final coat, the parting agent was air dried for one half hour. It was then oven dried for one hour at 150° F. One coat of Plastilease 334 was applied on all mandrel surfaces, air-dried, and then buffed lightly.

4. The polar head fittings were subsequently vapor degreased and etched per NAA Specification MA0106-002.

5. The exterior faying surfaces were then sprayed with Bondmaster M602 primer and cured per NAA Specification LS0106-008.

6. A layer of FM-97 was cut and applied to the outside surface of the flanges of each polar head fitting.

7. The polar fittings with attached adhesive were then placed in their respective places on the mandrel.

8. The mandrel was mounted in the horizontal winding machine and one layer of 0.012-inch thick winding, under 18 pounds of tension, was wrapped between the tangency points of the mandrel.

9. The assembly was then placed in the Rocketdyne vertical winding machine, and the first layer of (0.024-inch thick) roving under 18 pounds of tension, was wound longitudinally over the mandrel at a winding angle of 8 degrees.

10. A 0.5-inch wide, 0.006-inch thick, stainless steel trim strip was wrapped around the mandrel and centered on the trim lines located at the 7.00-inch stations.

11. Vinyl film 0.006-inch thick was installed in the cylindrical area of the mandrel in between the stainless steel trim strips.

12. The second cycle of longitudinal windings (0.020-inch thick) was then wrapped on under 10 pounds of tension and with the winding angle set at 9 degrees (Figure 44).

13. The partially wound mandrel was mounted in the horizontal winding machine, and 0.008-inch thick circumferential windings under 15 pounds of tension were wrapped on from the tangency points to the 7.00-inch station.

14. The second cycle of longitudinal winding wrapped on in step 12 was cut at the 7.00-inch station (both ends). The loose windings, vinyl film, and stainless steel trim strips were then removed.

15. Circumferential wraps 0.008-inches thick, under 15 pounds of tension, were wound over the exposed first layer of longitudinal windings between the 7.00-inch stations.

16. The case was then covered with dry No. 181 cloth and cured in the oven in the vertical position to the following schedule:

a. 2 hours - 250° F.
b. 6 hours - 300° F.
c. 2 hours - 350° F.

17. After removing the No. 181 dry cloth from the mandrel, the end skirt mold tooling was attached to the subscale case and the end skirt mandrel plaster, Kerr "DMM', was poured and allowed to dry. The other end skirt was molded in the same manner.

18. The subscale case with the molded end skirt molding was mounted in the horizontal or circumferential winding machine and plaster swept in any voids between the dome tanget line and the edge of the skirt mandrel plaster, and on the surface of the skirt mandrel. No. 150 grit sandpaper was used to smooth the mandrel surface and fair in areas where required.

19. A chromel-alumel thermocouple was inserted in the plaster at the dome tangency point and a longitudinal groove made in the skirt plaster so that the thermocouple lead would lay flush with the mandrel surface.

20. Several coats of Plastilease 334 parting agent were liberally applied to plaster skirt mandrels and then were lightly buffed when dried. Masking tape was wrapped on the windings near the tangency points to prevent accidentally coating these windings with parting agent. The tape was removed prior to the next operation.

21. Circumferential wraps 0.008-inch thick were wound (15 pounds of tension) on both ends starting at a point 0.25-inch beyond the skirt trim line and ending at the tangency line where these windings butted the partially cured circumferential windings on the case.

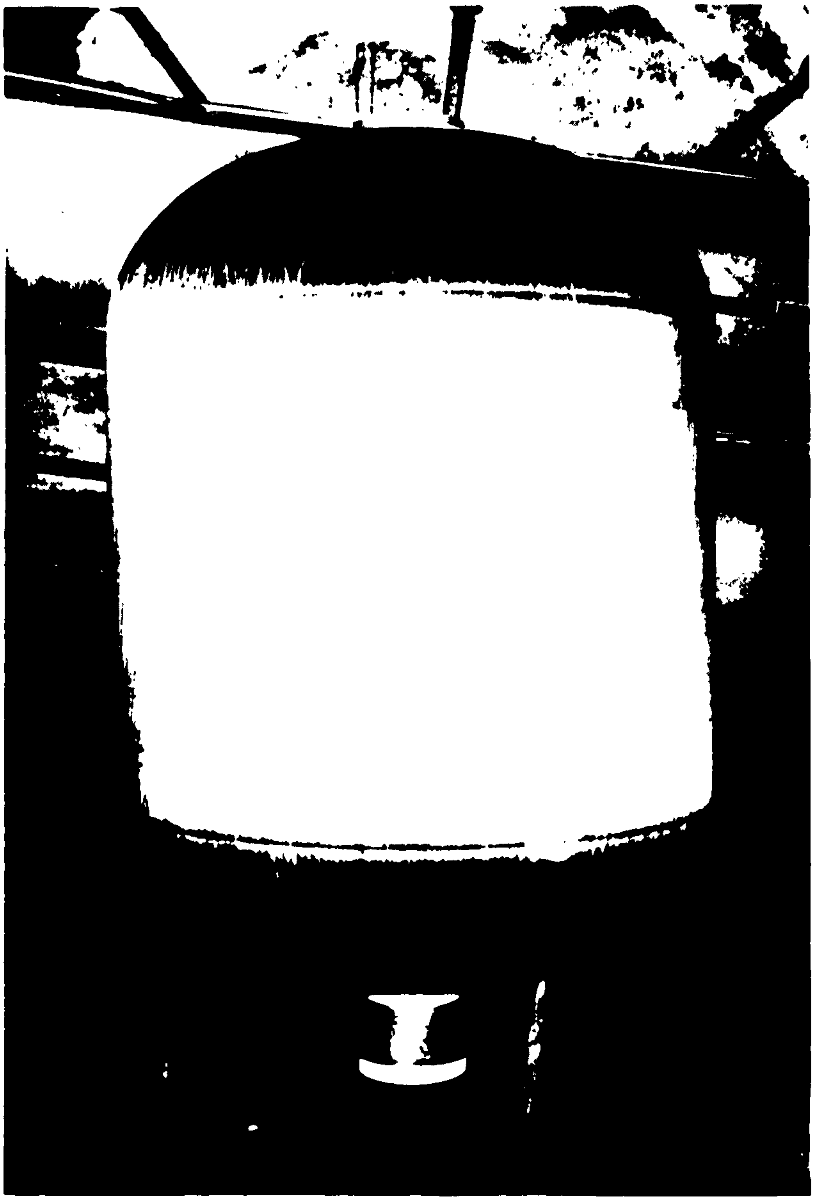


Figure 44. Subscale Case Before Trim

22. Four layers of preimpregnated unidirectional No. 143 cloth were cut to the dimensions in the drawing and applied over the 0.008-inch circumferential windings in the positions indicated in drawing Figure E-2. The warp of the No. 143 cloth was positioned to run parallel with the axis of the mandrel. A similar number and type of preimpregnated No. 143 cloth laminations were applied to the opposite end of the mandrel. In all instances the joints were of the butt type and staggered.

23. One layer of 0.008-inch circumferential windings was wrapped (under 15 pounds of tension) across the entire subscale case from a 0.25 inch point outside the right end skirt trim line to a 0.25 inch point outside the left end skirt trim line.

24. HT 432 adhesive film was applied to the cylindrical portion of the tank between the 7.00-inch stations. The adhesive was butted and not allowed to overlap in the longitudinal joint.

25. All six honeycomb core segments were cut 3/8-inch oversize and the edges of the core crushed back 3/16-inch in all edges in a manner commensurate with that used to form the small sandwich cylinder core segments. The joints were approximately as shown in Figure 37.

26. Each piece of cut core was cleaned and primed with HT 424F primer in accordance with NAA Specification MA0106-002.

27. HT 424 foam (0.1-inch thick) was taken from cold storage, allowed to warm to room temperature and then cut to the final dimensions (Step 25) of the four end skirt cores.

28. The separator was removed from the foam and one piece of foam properly positioned on inner surface of each of the end skirt core segment.

29. Working with one piece of core and foam at a time, the foam and core were placed in a 130° F oven for approximately 1 minute. When soft, the foam was quickly worked fully down into the core, and the foam filled core was removed from the oven and allowed to cool to room temperature.

30. A 0.5-inch wide piece of HT 424 foam was forced into the 0.25-inch section of core in the areas specified in the drawing in the manner described in step 27 through 29.

31. The two prepared 0.25-inch thick center section cores were positioned on the mandrel, and a 1/16-inch thick piece of HT 424 foam was added to the longitudinal butt splice joints (Figure 37). These two core sections were held in against the mandrel with loosely wound glass roving.

32. HT 432 adhesive film, cut 1-inch undersided in the width dimension, was applied to the outer surface of the center core segments, and one layer of 0.008-inch thick circumferential wraps (18 pounds of tension) was wound over the adhesive. The dry glass roving on each end of the center core sections was then removed.

33. A coat of U.S. Polymeric E787 formulation epoxy resin (similar to that resin used to impregnate the glass roving) was applied with a brush to both ends of the subscale case between 5.00-inch and 7.00-inch stations.

34. This area was then filled with nylon roving under 4 pounds of tension to meet the requirements of Figure E-2. Additional U.S. Polymeric E787 adhesive was applied between each layer.

35. A piece of FM-97 adhesive was cut and applied to both ends of the subscale case to cover the area from 7.00-inch station to a 0.5-inch point beyond the end skirt trim line.

36. The four 0.18-inch thick end skirt cores filled with foam were then positioned on each side of the center core sections with a 1/16-inch thick strip of HT 424 foam placed between all butting surfaces. A hair dryer-type heat gun was utilized from time to time to soften the butt joint foam and permit close honeycomb contact at the butt joints.

37. HT 432 adhesive film was cut and positioned over the remaining exposed center case and end skirt core segments.

38. The remainder of the first circumferential windings of the outer face was wound (18 pounds of tension) over the HT 432 adhesive on each of the end skirts and unwrapped section of the center case segments. The direction of the winding machine travel when applying these windings was always from the end of the skirt towards the point where these skirt winding butted the previously wound center windings.

39. One ply of preimpregnated. unidirectional No. 181 glass cloth was applied to both ends of the subscale case from 7.00-inch station to a 0.25-inch point beyond the end skirt trim line. A hair dryer-type heat gun was used to tack the preimpregnated cloth to the subscale case. The warp of the cloth ran in the longitudinal direction.

40. The mandrel and core with circumferential windings was then mounted in the vertical polar winding machine and one cycle of 0.016-inch longitudinal wraps wound on with an angle of 8 degrees and under 12 pounds of winding tension.

41. The mandrel and partially wound subscale case was then mounted in the horizontal machine and two plies of No. 143 preimpregnated glass cloth were

applied to each end of the mandrel with the individual layers trimmed to the dimension on the Figure E-2.

42. Two layers of 0.008-inch thick circumferential winding were wound (18 pounds of tension) over the entire length of the case, and excess longitudinal dome windings were removed to the end skirt trim lines.

43. The entire assembly was then mounted vertically in a curing fixture and cured in an oven to the following schedule:

a. 1 hour - 250°F.
b. 3 hours - 275°F.

Before the cure was continued, the partially cured subscale case was moved into a horizontal position while still in the oven and then the cure continued to 2 hours at 350°F. The temperatures were monitored with the thermocouple previously inserted in the subscale case at the tangency point (step 14).

44. The end skirt plaster and mandrel plaster was removed with water.

45. The subscale case was subsequently trimmed of excess material.

The difficulties that were encountered with the mandrels for subscale cases 5 and 6 are discussed in the section on tooling studies (Figures 27 and 45). After the shrinkage of the mandrel on subscale case 5 became apparent, together with the inhibition of the cure of the inner windings, it was decided to thoroughly bake out the mandrel for subscale case 6 and substitute a PVA/sand mixture for the skirt tooling.

Subscale Case 6

No. 6 filament-wound honeycomb rocket case was fabricated using the same materials and assembly procedures as those used on subscale case with the following deviations:

Steps 1 through 16 same as subscale case 5.

Step 17 was modified as follows: The mandrel material was changed from Kerr "DMM" to PVA/sand mixture which was not poured in place but tamped into the mold and dried.

Step 18 same as subscale case 5.

Step 19 was modified as follows: A PVA film was substituted for Plastilease 334 as the parting agent on the mandrel.

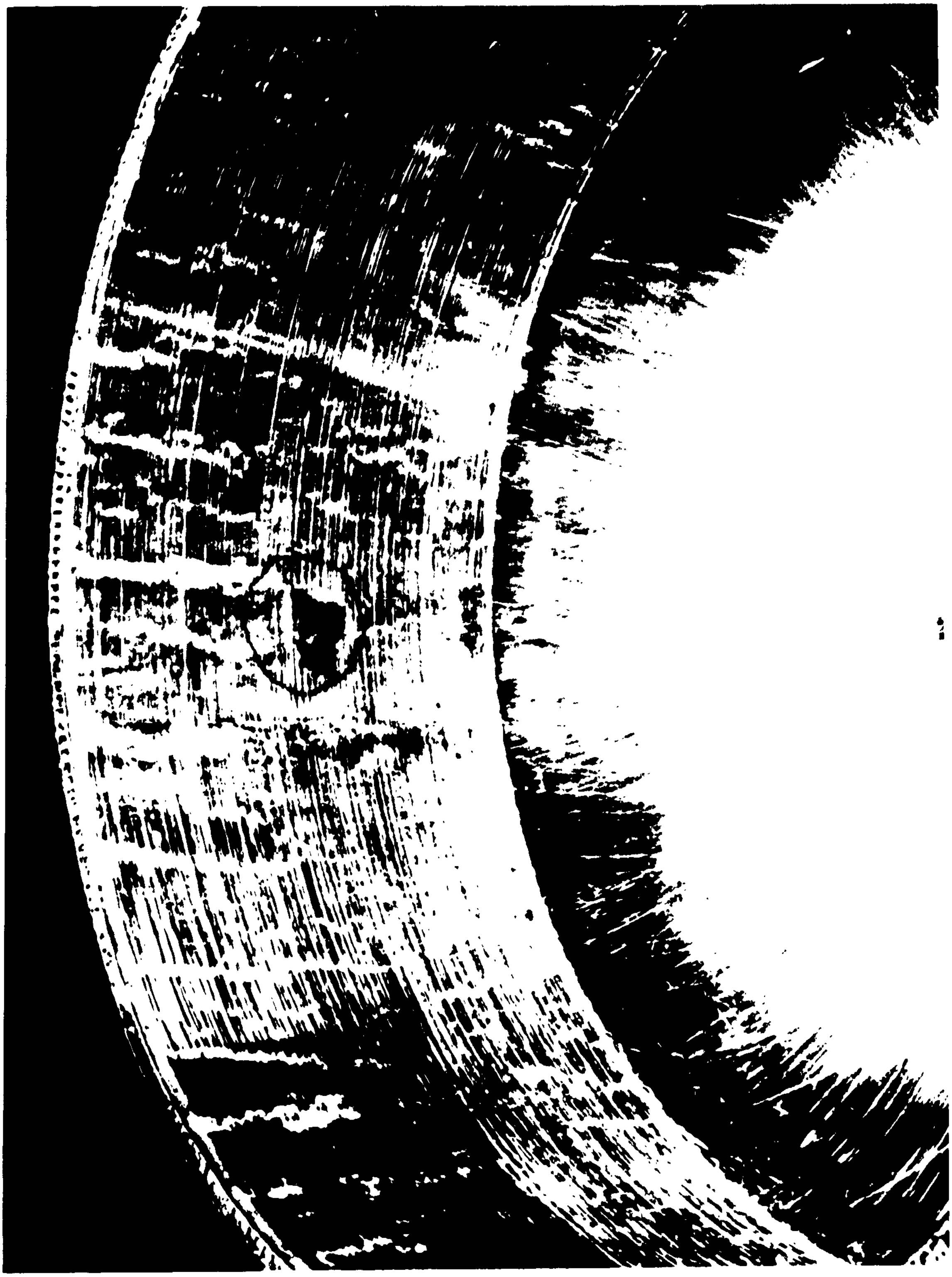


Figure 45. Inner Surface of Subscale Case 5

Steps 20 through 45 same as subscale case 5.

A PVA film had been positioned over the Kerr DMM skirt mandrels of subscale case 6 prior to applying the circumferential windings. These films apparently leached the resin from the inner circumferential windings during cure. After the mandrel was washed out, filaments appeared on the inner surface. There were no visible wrinkles or creases. A light brush coat of U.A. Polymeric E787 type resin was added to retain the filaments and the subscale case was placed in the oven at approximately 200°F to gel. During this operation several areas of the skirt buckled as previously discussed and illustrated. It is now assumed that the failure took place because of residual compression in the inner windings and because the resin softened sufficiently to permit failure.

Subscale case 6 was internally pressurized as described in the previous section. A leak developed in the valve attachment of the bladder at 610 psi, and the pressure dropped off. The specimen was tested again with a nitrogen pressure bottle attached to augment the capacity of the hydraulic test equipment. The case was pressurized with water until the pressure stabilized at 500 psi. The nitrogen pressure was then turned on. The internal pressure in the case increased to 700 psi, at which time a loud crack was heard. The pressure continued to increase to 940 psi, which corresponds to a stress of 156,000 psi in the circumferential wraps, and a stress of 108,000 psi in the longitudinal wraps. The domes were crazed and delamination was noted in the outer facing. Inspection of the case, after testing, indicated that no windings had been ruptured.

The test pressure of 940 psi exceeded the ultimate design pressure of 860 psi by 10 percent.

V. CONCLUSIONS

It is apparent from the foregoing remarks that the principal problem in the fabrication of the subscale cases can be attributed directly to the problems associated with the mandrels. Furthermore, it must be recognized that the intent of this program was primarily to establish the feasibility of fabricating a sandwich-type motor case, and as such, the program required a certain amount of toolproofing.

The mandrels used in phase II (subscale effort) were necessarily different from those to be used for phase III. Because of the size of the polar opening in the subscale cases, a wash-out plaster was required. However, for the full scale cases the polar opening is considerably larger, and it is possible to chip away, if necessary, the internal structure of the mandrel.

The plaster proposed for the full-scale mandrel is of the type which has been used successfully by other manufacturers in the production of filament-wound motor cases. Consequently, there is a high degree of assurance that the mandrels will be considerably better than those used for the subscale effort.

VI. RECOMMENDATIONS

Since the principal effort in the fabrication procedure — associated with phase II of this program — has now been stabilized, and since the problems associated with the mandrels have been resolved, it is recommended that the program be continued to completion.

APPENDIXES

APPENDIX A: Stress Analysis of Full-Scale Motor Case

APPENDIX B: Test Results of Sandwich-Wall Cylinders

APPENDIX C: Distribution List

APPENDIX D: Catalog Cards

APPENDIX E: Foldout Drawings

APPENDIX A

STRESS ANALYSIS OF FULL-SCALE MOTOR CASE

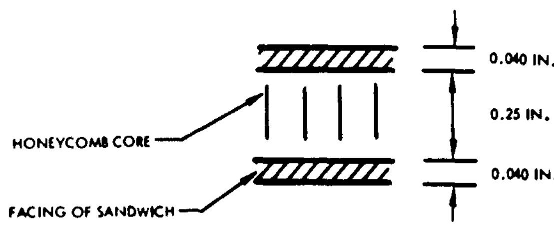
TENSION ANALYSIS

General Information

The tension allowable in the direction of the filament, as obtained from AMC 7-878 (I), is 160,000 psi at room temperature.

The limit internal pressure is equal to 300 psi.
The ultimate factor of safety is equal to 1.35.
The ultimate internal pressure is equal to 1.35 x 300 = 405 psi.
M.S. in the following equations represents Margin of Safety.

Motor Case Configuration



CROSS-SECTION OF SANDWICH

r (radius of cylinder) = 19 in.

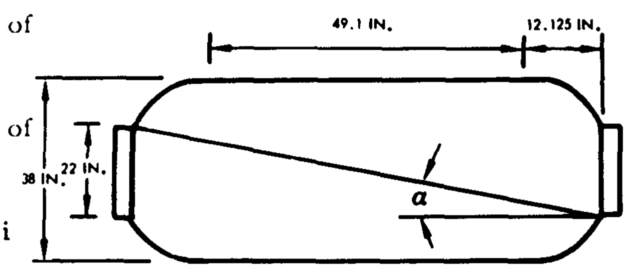
l (length of cylinder) = 49.1 in.

a (radius of polar fitting) = 11 in.

t_c = 0.048 in. = total thickness of of circumferential wraps

t_l = 0.032 in. = total thickness of longitudinal wraps

$p_{ultimate} = 300 \times 1.35 = 405$ psi



APPROXIMATE CONFIGURATION

Angle of Wrap for Longitudinal Filaments

The angle of wrap for the longitudinal filaments is determined as follows:

$$\tan \alpha = \frac{22}{49 + 2(12.125)} = 0.303$$

$$\alpha = 16.8°$$

Tensile Stress in Longitudinal Fibers

The tensile stress in the longitudinal fibers is determined as follows:

$$\sigma = \frac{pr}{2t_1 \cos^2 \alpha} = \frac{405 \times 19}{2 \times 0.032 \times \cos^2 16.8^{o}} = 131{,}000 \text{ psi}$$

$$\text{M.S.} = \frac{160{,}000}{131{,}000} - 1 = 0.22$$

Tensile Stress in Circumferential Fibers

The tensile stress in the circumferential fibers is determined as follows:

$$\sigma_c = \frac{pr}{t_c}\left[1 - \frac{\tan^2 \alpha}{2}\right] = \frac{405 \times 19}{0.048}\left[1 - \frac{0.092}{2}\right] = 153{,}000 \text{ psi}$$

$$\text{M.S.} = \frac{160{,}000}{153{,}000} = 0.05$$

COMPRESSION ANALYSIS

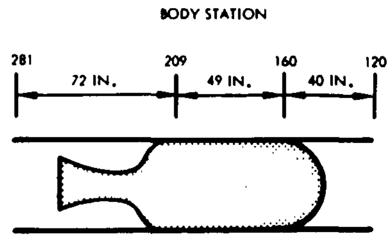
The purpose of this analysis was to check the compressive stresses in the motor case during the escape mission. Loads and temperatures during the trajectory were obtained from curves presented in AMC 7-878 (I).

Approximate Vehicle Size and Body Stations

$2\pi r = 119$ in. (circumference)

$1.5\pi r^2 = 1.70 \times 10^3$

$\pi r^2 = 1.13 \times 10^3$



Body station 209 was used to determine all compressive stresses.

Maximum q Condition

M_u (ultimate moment) = $0.4 \times 10^6 \times 1.35 = 5.4 \times 10^5$ in-lb

X_u (ultimate axial load) = $30 \times 10^3 \times 1.35 = 4.05 \times 10^4$ lb

$$Nx_F \text{ (outer fiber load/in.)} = \frac{4.05 \times 10^4}{1.19 \times 10^2} + \frac{5.4 \times 10^5}{1.13 \times 10^3} = 3.4 \times 10^2 + 4.8 \times 10^2$$

$$= 820 \text{ lb/in.}$$

$$Nx_B \text{ (effective buckling load/in.)} = 3.4 \times 10^2 + \frac{5.4 \times 10^5}{1.7 \times 10^3} = 3.4 \times 10^2 + 320$$

$$= 660 \text{ lb/in.}$$

<u>End Boost of First Stage</u>

$$M_u = 0.5 \times 10^6 \times 1.35 = 6.75 \times 10^5 \text{ in.-lb}$$

$$X_u = 0.4 \times 10^4 \times 1.35 = 5.4 \times 10^4 \text{ lb}$$

$$Nx_F = \frac{5.4 \times 10^4}{1.19 \times 10^2} + \frac{6.75 \times 10^5}{1.13 \times 10^3} = 453 + 600 = 1053 \text{ lb/in.}$$

$$Nx_B = 453 + 400 = 853 \text{ lb/in.}$$

<u>End Boost of Second Stage</u>

$$M_u = 0$$

$$X_u = 3.5 \times 10^4 \text{ lb}$$

$$Nx_F = 3.5 \times 10^4 = 295 \text{ lb/in.}$$

$$Nx_B = 295 \text{ lb/in.}$$

The maximum loading condition is end boost first stage.

<u>Maximum Outer Fiber Stress</u>

$$\sigma = \frac{1053}{0.080} = 13{,}200 \text{ psi}$$

<u>Effective Buckling Stress</u>

$$\sigma = \frac{853}{0.080} = 10{,}600 \text{ psi}$$

Material Compression Properties

If 0.07 cork insulation is used, the temperature at end boost first stage is approximately 150°F in the outer facing.

The compression allowable at 150°F is 14,000 psi.

$$\therefore \text{ M.S.} = \frac{14{,}000}{13{,}200} - 1 = + 0.06$$

Honeycomb Core Properties

The core materials will be 5052-H39 hexagonal aluminum honeycomb core, 3.1 lb/ft^3 density. The allowable flatwise compressive strength is 270 psi and the flatwise compressive modulus is 10^5 psi.

The longitudinal shear modulus is 24,000 psi.
The transverse shear modulus is 12,000 psi.

Flatwise Compressive Stress in Core

$$\sigma_{actual} = \frac{p}{2 + \left(\frac{Etc}{r^2 E_c}\right)} \approx p/2 = 203 \text{ psi}$$

$$\therefore \text{ M.S.} = \frac{270}{203} - 1 = + 0.34$$

Allowable Buckling Stress

Forest Products Laboratory Report Number 1876 was used as the reference for this stability analysis. The nomenclature in this analysis is the same as that employed in Report Number 1876.

$\mu_{\rho x} = 24{,}000$ psi

$\mu_{oy} = 12{,}000$ psi

$c = 0.25$ in.

$h = 0.33$ in.

$f_1 = f_2 = 0.040$

$r = 19.165$

$\lambda = 1 - (0.15)^2 = 0.978$

$E \approx 3 \times 10^6$ at 150°

$$\phi = \frac{cf}{2} = \frac{0.25 \times 0.04}{2} = 0.005$$

$$S_x = \frac{2\phi E}{3\lambda\mu\rho_x rh} = \frac{2 \times 5 \times 10^{-3} \times 3 \times 10^6}{3 \times 0.978 \times 2.4 \times 10^4 \times 19.165 \times 0.33}$$

$$\alpha = \sqrt{\frac{E_x}{E_y}} = \sqrt{\frac{3 \times 10^6}{4.5 \times 10^6}} = 0.81$$

$$\beta = \alpha\sigma_{yx} + 2\gamma = 0.81 \times 0.15 + 2(0.247) = 0.621$$

$$\gamma = \frac{\lambda\mu_{xy}}{\sqrt{E_x E_y}} = \frac{0.978 \times 1 \times 10^6}{\sqrt{3 \times 10^6 \times 4.5 \times 10^6}} = 0.247$$

From an IBM program which solves Forest Products Laboratory's equations, the following results were obtained:

$N = 0.952 \qquad Q_1 = 2.24 \qquad L_o = 0.98 \qquad z_{min} = 1.05 \qquad \eta_{min} = 0.202$

$$\sigma_{cr} = \frac{NL_o}{Q_1} E \times \frac{h}{r} = \frac{0.952 \times 0.98 \times 3 \times 10^6 \times 0.33}{2.24 \times 19.165}$$

$$\sigma_{cr} = 21{,}400 \text{ psi}$$

$$n^2 \frac{h}{r} = \eta$$

$$n = \sqrt{\frac{\eta r}{h}} = \sqrt{\frac{0.202 \times 19.16}{0.33}} = \sqrt{11.7} = 3.43$$

Assuming four buckles in a circumferential direction, then:

$$\text{the wavelength of each buckle} \approx \frac{\pi \times 38.3}{4} = 30 \text{ in.}$$

$$\therefore \text{ M.S.} = \frac{21{,}000}{10{,}600} - 1 = +1.02$$

Wrinkling Stress

The following equation is obtained from "The Buckling of Sandwich-Type Panels" by N. J. Hoff and S. E. Mautner, as published in the Journal of Aeronautical Sciences, July, 1945:

$$\sigma_{wr} = 0.5 \sqrt[3]{E_c G_c E} = 0.5 \sqrt{10^5 \times 2.4 \times 10^4 \times 3 \times 10^6} = 96{,}500 \text{ psi}$$

Not critical.

Dimpling Stress

The following equation is obtained from "Sandwich Construction for Aircraft," Part II, AMC-23:

$$\sigma_D = 0.9E\left(\frac{t}{S}\right)^{3/2} = 0.9 \times 3 \times 10^6 \left(\frac{0.04}{0.375}\right)^{1.5} = \frac{0.9 \times 3 \times 10^6}{29} = 930{,}000 \text{ psi}$$

Not critical.

ANALYSIS OF POLAR FITTING

Bending Stress in Flange.

The following analysis of the polar fitting is based on the assumption that 1-1/2 inches of flange is effective in bending, and that the flange is a constant 0.39 inch of thickness:

$$A = \frac{\pi 22^2}{4} = 380 \text{ in.}^2$$

$$F = 380 \times 406 = 1.540 \times 10^5 \text{ lb}$$

$$A_\theta = \frac{\pi(25)^2}{4} = 490 \text{ in.}^2$$

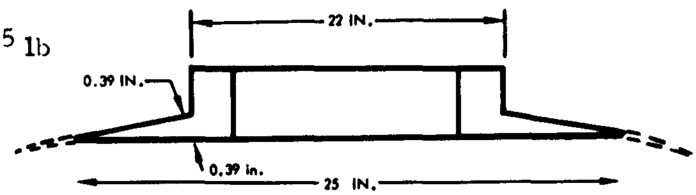
$$A_F = 490 - 380 = 110 \text{ in.}^2$$

$$p = \frac{1.54 \times 10^5}{1.1 \times 10^2} = 1.4 \times 10^3 \text{ psi}$$

$a = 12.5$ in.

$b = 11$ in.

$\mu \approx 1/3$



POLAR FITTING

Material is 7075-T6
All allowables for materials and fasteners were obtained from S&ID Structures Manual AL 1444

The following equation for the maximum bending stress in the flange was obtained from "Formulas for Stress and Strain" by Roak:

$$\sigma = \frac{3p}{4t^2}\left[\frac{4a^4\left(\frac{1}{\mu}+1\right)\log\frac{a}{b} - a^4\left(\frac{1}{\mu}+3\right) + b^4\left(\frac{1}{\mu}-1\right) + 4a^2b^2}{a^2\left(\frac{1}{\mu}+1\right) + b^2\left(\frac{1}{\mu}-1\right)}\right]$$

$$\sigma = \frac{0.75\,p}{(0.39)^2}\left[\frac{4 \times 2.45 \times 10^4(4)\,0.131 - 2.45 \times 10^6(6) + 1.46 \times 10^4(2) + 4(121)(156)}{156(4) + 121(2)}\right]$$

$$\sigma_{actual} = \frac{0.75\,p}{(0.39)^2}[10.4] = \frac{0.75 \times 1.4 \times 10^3}{(0.39)^2}\ 10.4 = 71{,}000 \text{ psi}$$

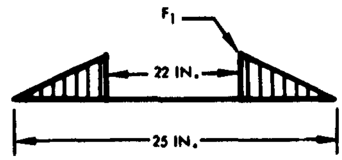
$$\sigma_{all} = 71{,}000 \text{ psi}$$

$$\therefore \text{M.S.} = \frac{71{,}000}{71{,}000} - 1 = 0$$

Bearing Stress

The following equation for bearing stress between the flange and the dome is based on the assumption that the distribution of bearing stress is triangular:

$$V = 1/3 \left(A_2 - 2A_1 + \sqrt{A_2 A_1}\right) F_1$$



$A_1 = 380$ psi

$A_2 = 568$ psi

$\sqrt{A_1 A_2} = \sqrt{21.6 \times 10^4} = 465$ psi

$V = 1.54 \times 10^5$

$V = 1/3\,(568 - 760 + 465)\,F_1$

$V = 1/3\,(273)\,F_1$

$$F_1 = \frac{3V}{273} = \frac{3 \times 1.54 \times 10^5}{273} = 1.59 \times 10^3 = 1590 \text{ psi}$$

The allowable bearing stress is 3000 psi:

$$\therefore \text{ M.S.} = \frac{3000}{1590} - 1 = +\,.79$$

Stress and Deflection for Cover Plate

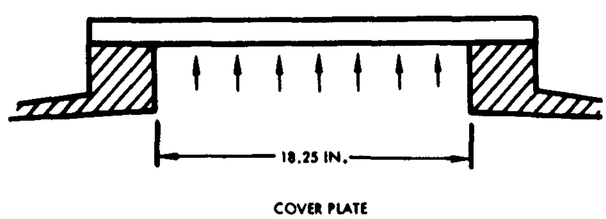
The stress and deflection for the cover plate are determined by the following equations:

$p = 405$ psi ultimate

$\sigma_{all} = 71{,}000$ psi

$$A = \frac{\pi (18.25)^2}{4} = 262 \text{ in.}^2$$

$P = pA = 406 \times 262 = 106{,}000$ lb



Material is 7075-T6

The following equations for stresses and deflects were derived from "Theory of Plates and Shells" by Timoshenko:

Clamped Edges:

$$\sigma = \frac{3pr^2}{4t^2} = \frac{3 \times 406 \times (9.1)^2}{4 \times (0.75)^2} = 45{,}000 \text{ psi ultimate}$$

Simply-Supported Edges:

$$\sigma = \frac{3(3+\mu)}{8} \quad \frac{pr^2}{t^2} = 1.24 \times 406 \left(\frac{9.1}{0.75}\right)^2 = 74{,}000 \text{ psi ultimate}$$

Stress will not be critical because actual stress will be somewhere between 45,000 and 74,000 psi.

Deflection at Center for Simple Support:

$$\omega_{simple} = \frac{5.3}{83.5} \quad \frac{pr^4}{D} = \frac{5.3 \times 406 \times 69 \times 10^2}{83.5 \times 3.83 \times 10^5} = 0.467 \text{ in.}$$

Deflection at Center for Clamped Edges:

$$\omega_{fixed} \approx \frac{0.467}{4} = 0.117 \text{ in.}$$

Analysis of Bolts Which Hold Cover Plate

Tensile Strength:

36 bolts are used to hold the cover plate to the polar fitting. AN6 bolts were used.

$$\text{force/bolt} = \frac{106{,}000}{36} = 2950 \text{ lb}$$

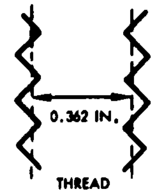
The allowable load per bolt is 3800 lb

$$\therefore \text{ M.S.} = \frac{3800}{2950} - 1 = +0.29$$

Pull Out of Bolts:

$F_{su} = 5 \times 10^4$ psi

Assume that 1/2-length of bolt is effective in shear



Thread depth = 0.563 in.
Mean diameter = 0.362 in.

Effective shear area:

$$A_s = \pi 0.362 \times \frac{0.563}{2} = 3.19 \text{ in.}$$

Shear out strength/bolt = $3.19 \times 5 \times 10^5 = 1.6 \times 10^5$ lb

Not critical.

Bearing Under Head of Bolt

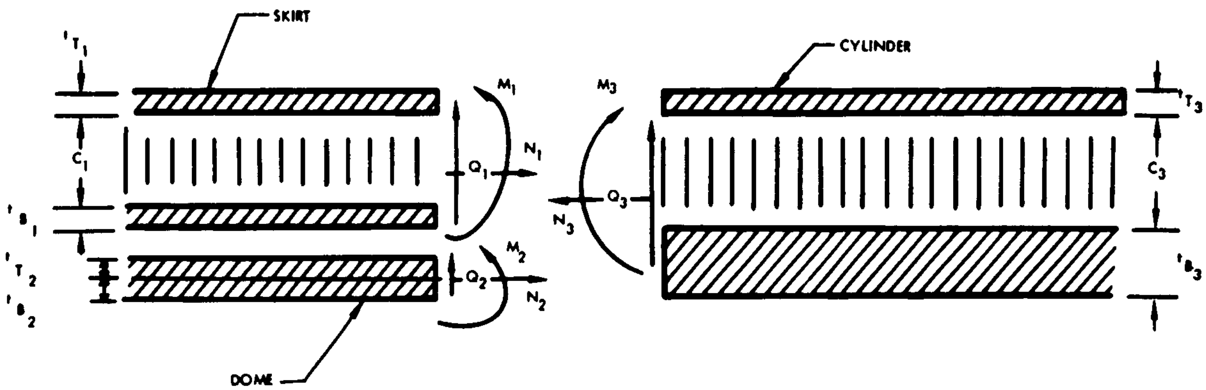
$$A = \pi/4\,(0.53^2 - 0.375^2) = 0.127$$

$$\sigma = \frac{2950}{0.127} = 23{,}200 \text{ psi}$$

Not critical.

DISCONTINUITY STRESSES AT JOINT

The Idealized Model



NOTE: Subscript B pertains to the bottom facing; Subscript T pertains to the top facing; Subscripts 1, 2, and 3 pertain to the skirt, dome, and cylinder respectively.

Material Properties

Symbols:

Ex - Young's modulus of the facing sheet in the direction parallel to the longitudinal axis of the cylinder.

Ey - Young's modulus of the facing sheet in the circumferential direction.

Skirt:

$Ex_{B_1} = 3.3 \times 10^6$	$t_{B_1} = 0.046$	$Ey_{B_1} = 3.1 \times 10^6$
$Ex_{T_1} = 4 \times 10^6$	$t_{T_1} = 0.060$	$Ey_{T_1} = 3.5 \times 10^6$
	$c_1 = 0.19$	

Dome:

$Ex_{B_2} = 7 \times 10^6$	$t_{B_2} = 0.024$	$Ey_{B_2} = 1 \times 10^6$
$Ex_{T_2} = 7 \times 10^6$	$t_{T_2} = 0.024$	$Ey_{T_2} = 1 \times 10^6$
	$c_2 = 0$	

Cylinder:

$Ex_{B_3} = 4.9 \times 10^6$	$t_{B_3} = 0.093$	$Ex_{B_3} = 2.6 \times 10^6$
$Ex_{T_3} = 4.9 \times 10^6$	$t_{T_3} = 0.060$	$Ey_{T_3} = 3.5 \times 10^6$

Shear modulus of foam-filled core = 100,000 psi
Shear strength of foam-filled core = 2000 psi

Membrane Deflection in the Radial Direction

$$\delta_1 = 0$$

$$\delta_2 = \frac{40^5 \times (19.16)^2 \times 0.04}{2 \times 1 \times 10^6 \times 0.048} = -0.062$$

$$\delta_3 = \frac{405 \times (19.16)^2 \times 0.925}{3.5 \times 10^6 \times 0.06 + 0.092 \times 2.6 \times 10^6} = \frac{13.7 \times 10^4}{44.9 \times 10^4} = 0.305$$

$C_1 = 0.19$

$C_2 = 0$

$C_3 = 0.20$

Membrane Forces in the Longitudinal Direction

$N_1 = 0$

$$N_2 = \frac{405 \times 19.16}{2} = 3880 \text{ lbs/in.}$$

$N_3 = 3880$ lbs/in.

Results

Using the material and geometrical properties, the forces Q_1, Q_2, Q_3, M_1, M_2 and M_3 can be found by employing the method described in AMC 7-878 (I). The computations were made with an IBM computer. The results are as follows:

$$M_1 = -213 \frac{\text{in. -lb}}{\text{in.}} \qquad Q_1 = 266 \text{ lb/in.}$$

$$M_2 = -17 \frac{\text{in. -lb}}{\text{in.}} \qquad Q_2 = 32 \text{ lb/in.}$$

$$M_3 = 222 \frac{\text{in. -lb}}{\text{in}} \qquad Q_3 = -297 \text{ lb/in.}$$

The stresses caused by these forces were superimposed on the stresses caused by membrane forces; comparison with the allowable stresses resulted in positive safety margins in all sections.

APPENDIX B

TEST RESULTS OF SANDWICH-WALL CYLINDERS

INTRODUCTION

The test reported herein fulfill the obligations of a section of Contract AF 33(600)43031, entitled, "Sandwich Rocket Motor Case Program."

PURPOSE

The purpose of the following tests was to determine the ultimate axial compressive strength and both axial and circumferential deflections of 6 sandwich-wall cylinders simulating filament-wound rocket motor cases.

TEST SPECIMEN

Six small-scale sandwich cylinders were fabricated at the Rocketdyne Division in cooperation with S&ID engineers. All cylinders were made by filament-winding techniques, using uni-directional glass cloth and glass roving in conjunction with epoxy laminating resin, as described in AMC Interim Report 7-878 (I). The core of the sandwich wall consisted of Multi-wave aluminum honeycomb. Dimensional data are recorded in Table B-1 and the coordinate system employed to derive the data is illustrated in Figure B-1.

RESULTS

The test results are listed in Table B-1. A summary of ultimate stresses and the compressive modulus is presented in Table B-2. Photographs of typical failure specimens are offered in Figures B-2 and B-3.

PROCEDURE

The sandwich test cylinders were prepared by casting the ends into special loading plates. A circular groove, 3/8-inch deep and 7/8-inch wide, was machined into the plates. The cylinders were shimmed above the groove bottom by 1/16-inch washers, and the groove was filled with activated epoxy resin.

Table B-1. Dimensions, Strengths, and Resin Content of Sandwich-Wall Cylinders

Spec. No.	Ordinate No. *	Wall thickness at stations (in.)			Inside face thickness (in.)			Outside face thickness (in.)			Inside diameter at station (in.)			Overall Length (in.)	Resin Content (percent)	Failing Load (lb)**
		A	B	C	A	B	C	A	B	C	A	B	C			
1	1	0.578	0.573	0.575	0.040	0.033	0.035	0.047	0.040	0.040	8.471	8.471	8.476	10.07	16.72	55,000
	3	0.576	0.577	0.575	0.044	0.038	0.045	0.046	0.047	0.042				10.07	(inside wall)	
	2	0.571	0.573	0.573							8.472	8.472	8.475	10.07	18.33	
	4	0.570	0.569	0.571										10.07	(outside wall)	
2	1	0.577	0.571	0.570	0.041	0.041	0.039	0.041	0.043	0.039	8.471	8.471	8.476	9.96	16.59	48,250
	3	0.572	0.574	0.570	0.041	0.037	0.039	0.040	0.041	0.040				9.96	(inside wall)	
	2	0.574	0.572	0.571							8.472	8.472	8.475	9.96	20.68	
	4	0.575	0.571	0.572										9.96	(outside wall)	
4	1	0.611	0.612	0.612	0.037	0.037	0.037	0.041	0.043	0.040	8.428	8.429	8.427	9.96	18.21	46,250
	3	0.609	0.607	0.598	0.037	0.040	0.036	0.042	0.042	0.041				9.96	(inside wall)	
	2	0.582	0.581	0.581							8.495	8.497	8.499	9.96	20.49	
	4	0.583	0.579	0.579										9.96	(outside wall)	
5	1	0.585	0.584	0.585	0.032	0.037	0.036	0.040	0.042	0.043	8.486	8.482	8.482	10.00	19.47	49,500
	3	0.588	0.585	0.590	0.032	0.038	0.037	0.043	0.042	0.041				10.00	(inside wall)	
	2	0.585	0.583	0.585							8.488	8.484	8.484	10.00	20.10	
	4	0.589	0.581	0.585										10.00	(outside wall)	
6	1	0.599	0.597	0.599							8.488	8.491	8.490	9.950		58.250
	3	0.599	0.598	0.597										9.950		
	2	0.599	0.595	0.597							8.481	8.480	8.484	9.950		
	4	0.599	0.595	0.597										9.950		
7	1	0.607	0.600	0.609	0.049	0.052	0.059	0.050	0.054	0.057	8.490	8.486	8.485	10.00		25,000
	3	0.605	0.602	0.599	0.048	0.047	0.059	0.057	0.049	0.055				10.00		
	2	0.604	0.600	0.600							8.490	8.487	8.486	10.00		
	4	0.595	0.593	0.599										10.00		

*For coordinate system, see Figure XX
**Location of failure was at center for all cylinders

The load was applied in increments of 10,000 pounds. Axial and circumferential deflections were read from dial gages at these intervals. Loading was continued until failure occurred. (For load-deflection curves, see Figures B-4 through B-8; for detailed test data, refer to Table B-3.)

Cylinder 1 had also been instrumented with 3 electric strain gages, oriented axially, and spaced at 120-degree intervals around the midsection of the cylinder. Cylinder 6 was used for photoelastic coating studies in the lower loading ranges, and quantitative deflection data were not obtained due to an inadequate bond between the coating and the glass wrapping.

Cylinder 7 was heated to 160°F for 1.5 hours; 180°F for 1 hour; then to 200°F for another hour. Finally, the cylinder was heated to approximately 210°F and then tested. (See Figure B-9 for load-deflection and temperature data.) Load intervals were at 5000 pounds.

The resin content of the cylinder walls was determined by cutting specimens from the cylinders that had failed, then by removing excess adhesive and by heating the specimens at 1050°F until constant weight was achieved.

Table B-2. Sandwich-Wall Cylinder Test Results

Material Properties	Cylinders					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Ultimate compressive stress	23,700	21,700	21,200	23,400	26,400	8,500
Compressive modules	3.31×10^6	3.85×10^6	4.6×10^6	5.65×10^6		2.6×10^6.

Table B-3. Load-Deflection Data For Sandwich-Wall Cylinders

Specimen No.	Load x 10^{-3} (lb)	Deflection (Mils)		
		Axial Right	Axial Left	Circumference
1	10	5.8	7.4	0.8
	20	10.0	14.6	6.7
	30	16.4	21.8	9.9
	40	21.6	26.5	16.8
	50	27.4	36.9	22.7
2	10	5.0	4.5	0.0
	20	10.4	10.3	4.9
	30	16.0	15.9	5.9
	40	22.2	22.4	13.0
3	10	5.8	7.4	0.8
	20	11.0	14.6	6.7
	30	16.4	21.8	9.9
	40	21.6	29.5	16.8
	50	37.4	36.9	22.7
4	10	0.2	3.6	4.1
	20	0.4	8.7	8.8
	30	20.0	13.6	13.7
	40	55.0	18.9	18.7
5	no deflection measurements			
6*	5	2.8	5.1	0.0
	10	6.5	9.5	0.1
	15	10.8	15.1	0.1
	20	16.6	25.8	0.1
	25	40.0	40.3	0.7

*At 210°F

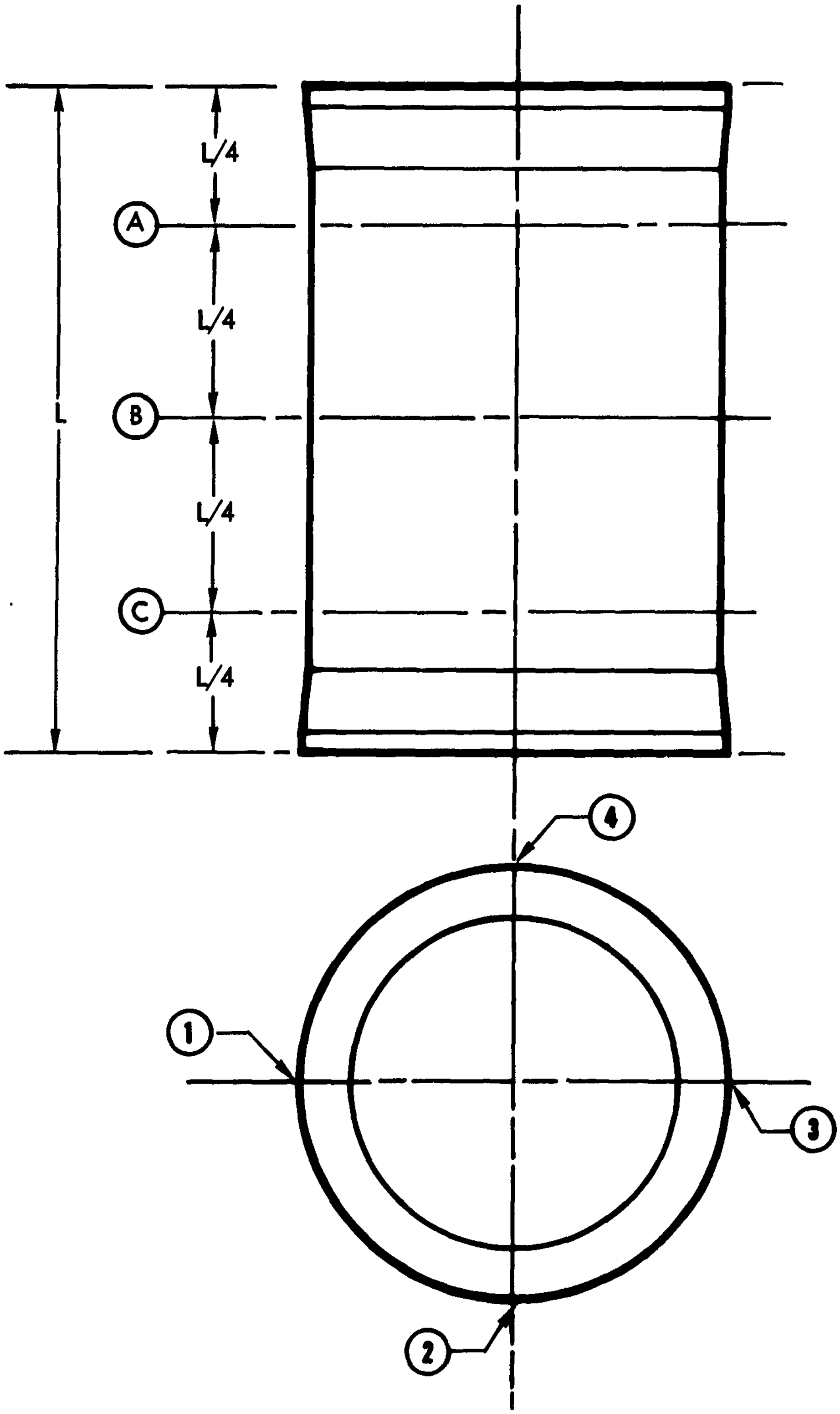


Figure B-1. Coordinate System for Sandwich-Wall Cylinders

Figure B-2. Sandwich-Wall Cylinder 1 After Test

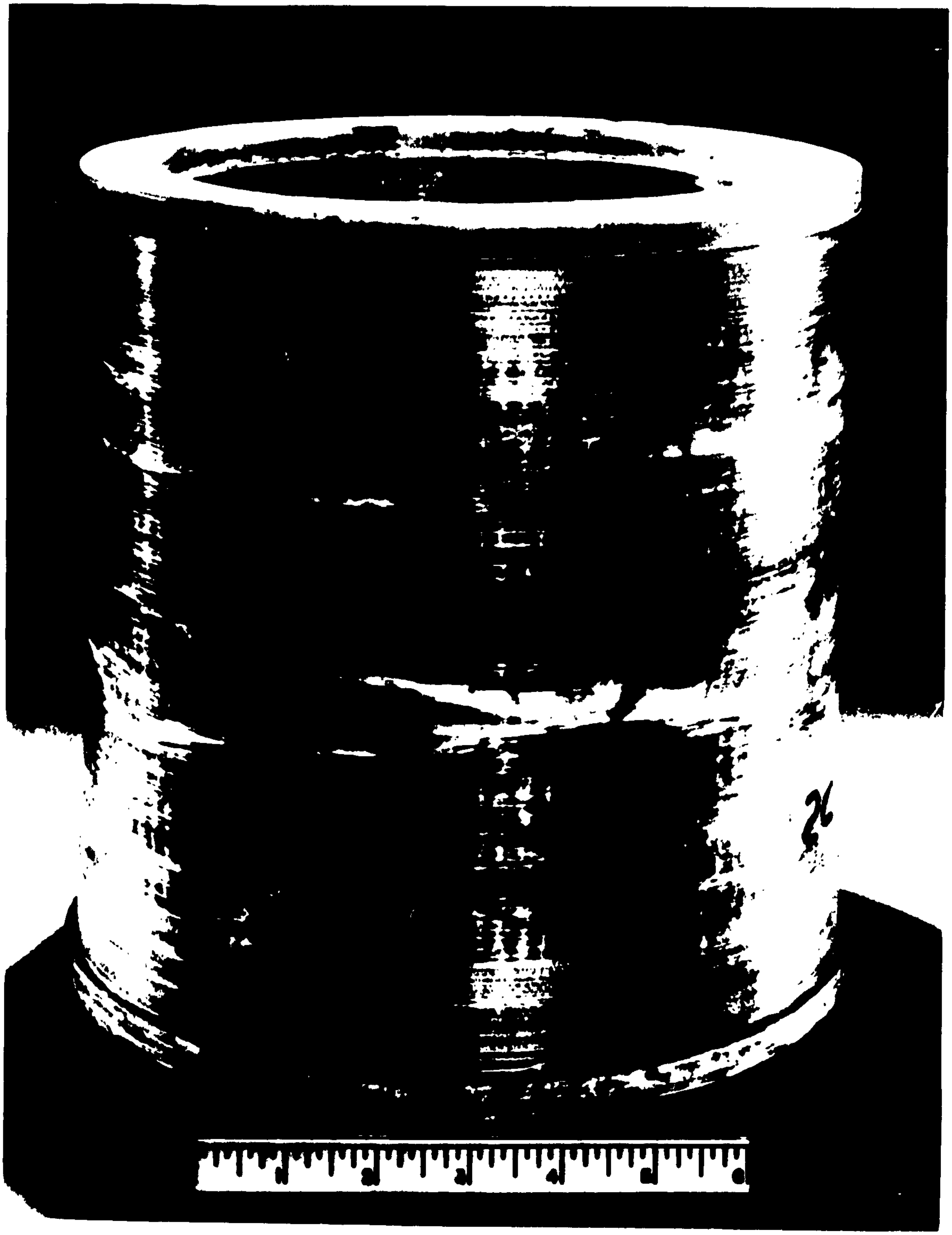


Figure B-3. Sandwich-Wall Cylinder 7 After Test

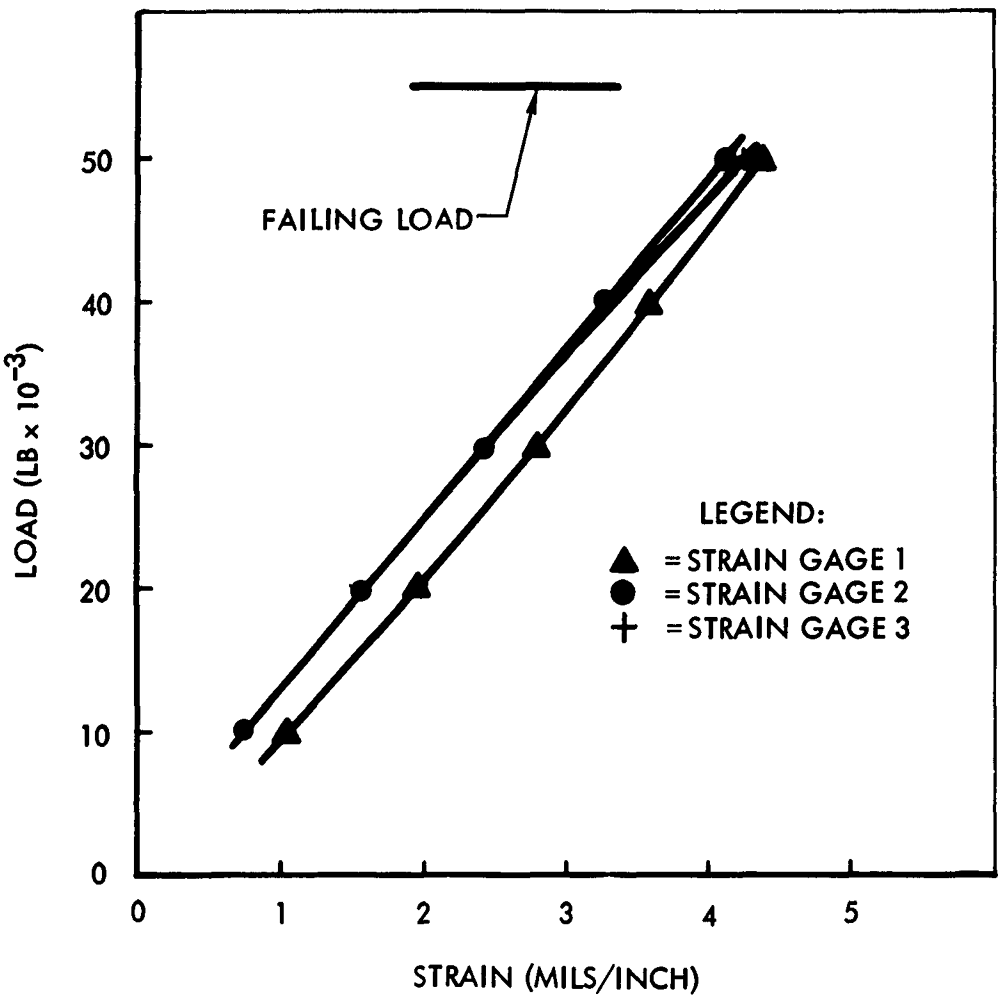


Figure B-4. Load-Strain Curves for Sandwich-Wall Cylinder 1

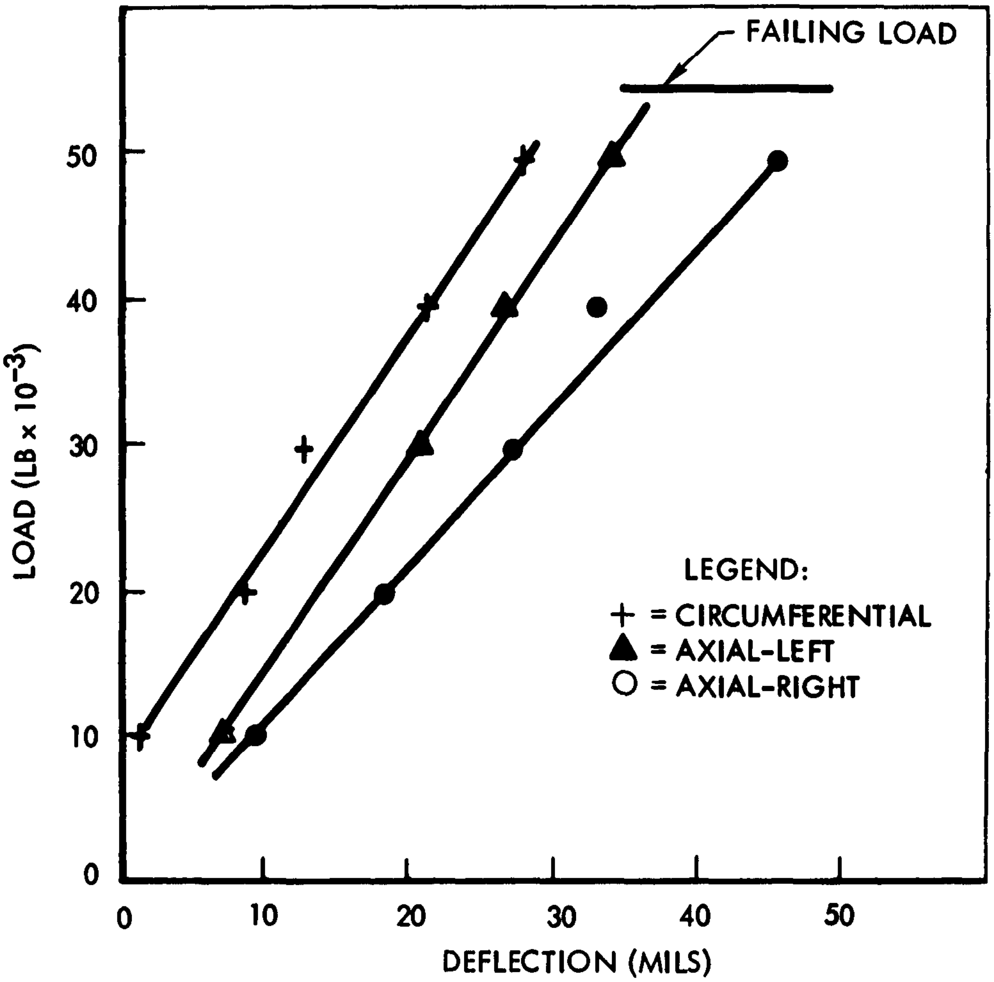


Figure B-5. Load-Deflection Curves for Sandwich-Wall Cylinder 1

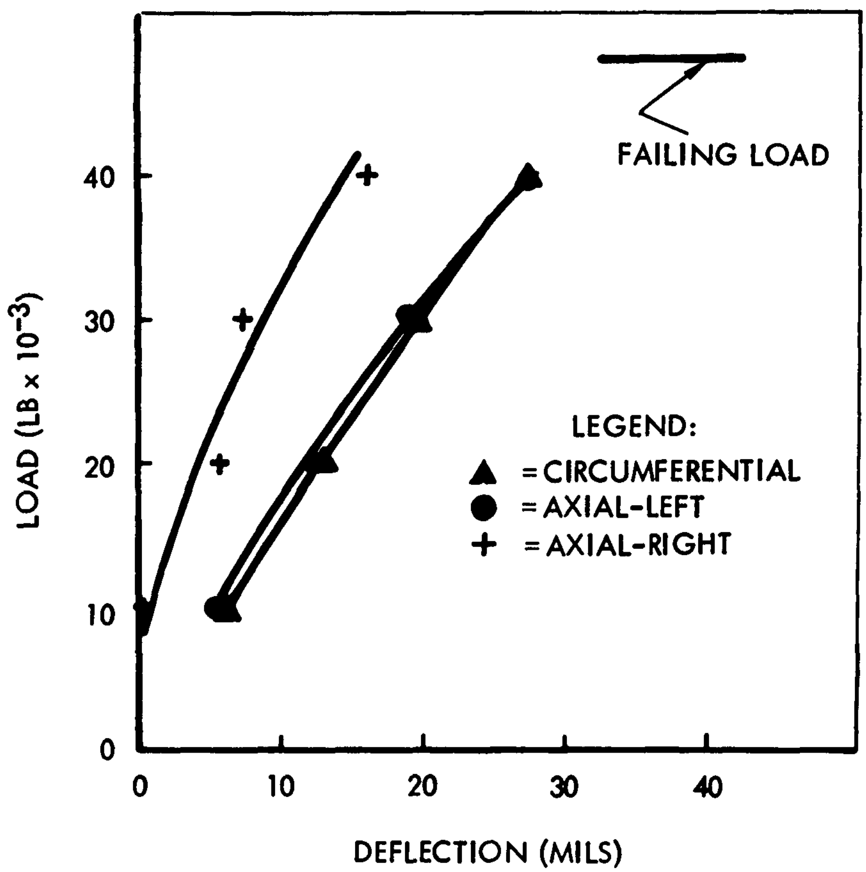


Figure B-6. Load Deflection Curves for Sandwich-Wall Cylinder 2

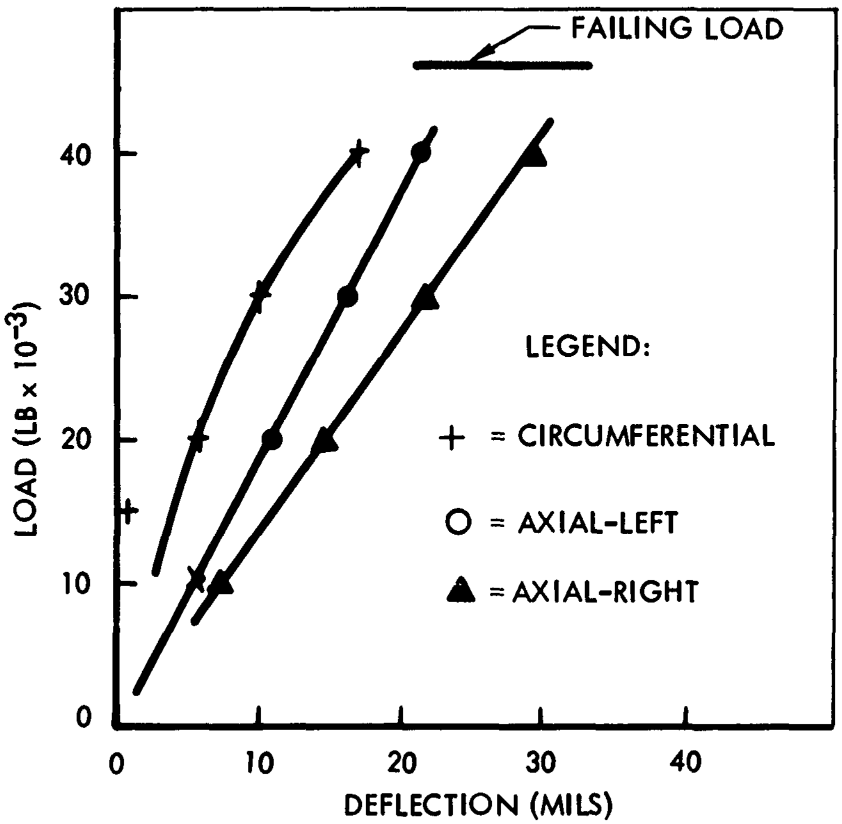


Figure B-7. Load-Deflection Curves for Sandwich-Wall Cylinder 4

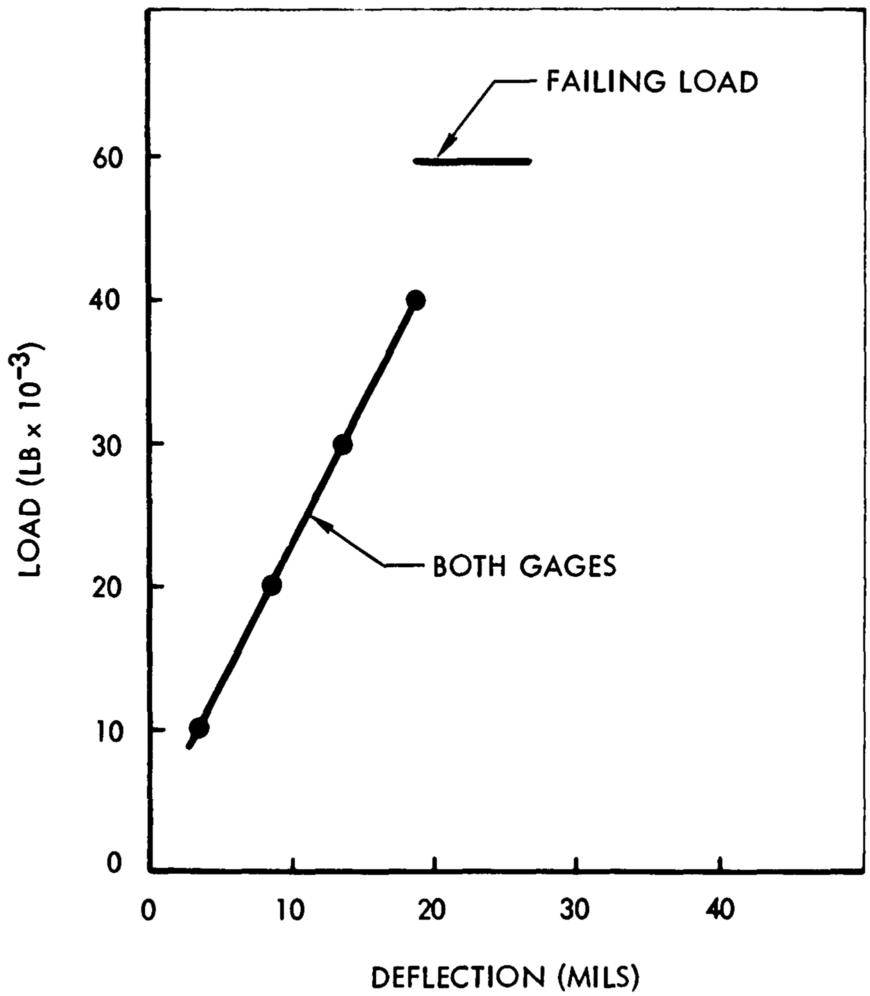


Figure B-8. Load-Deflection Curves for Sandwich-Wall Cylinder 5

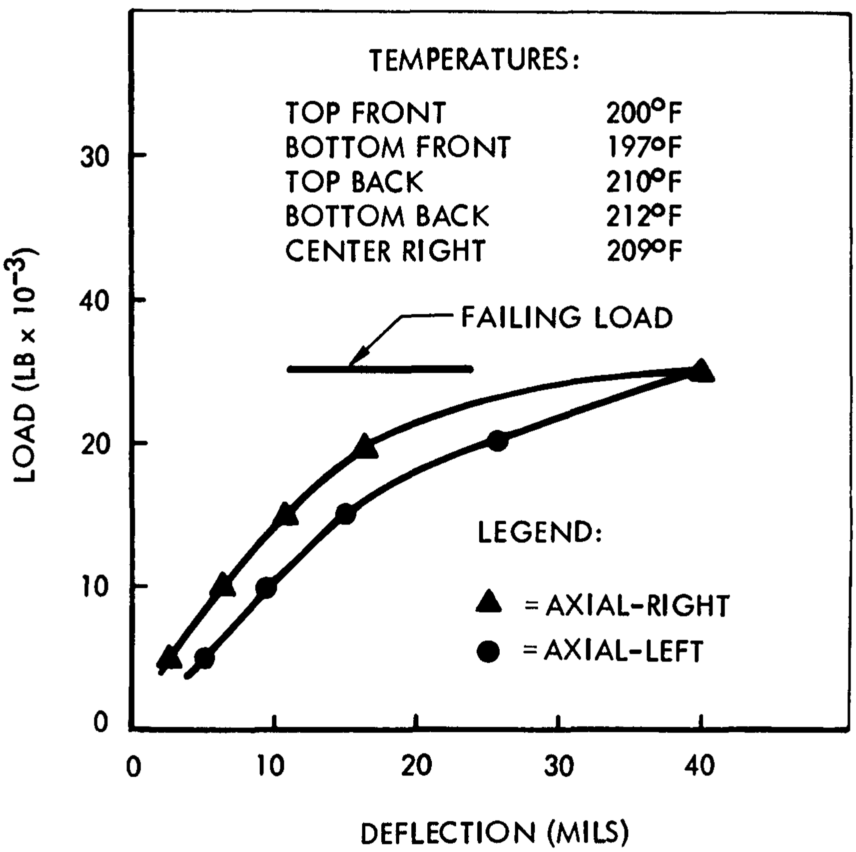


Figure B-9. Load-Deflection Curves for Sandwich-Wall Cylinder 7

APPENDIX C

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44p. incl. illus. tables. (Proj. 7-878)
(Interim Technical Engineering Report No ASD 7-878 (II))
(Contract AF33(600)-43041)
Unclassified Report

Describes fabrication studies and tests to determine material allowables together with description of sub-scale and full-scale filament-wound sandwich rocket motor case.

UNCLASSIFIED

1. Materials:
   Filament-wound
   Fiberglass
2. Plastic Sandwich Construction
3. Weight Comparison
4. Structural Analysis
5. Filament Winding Techniques

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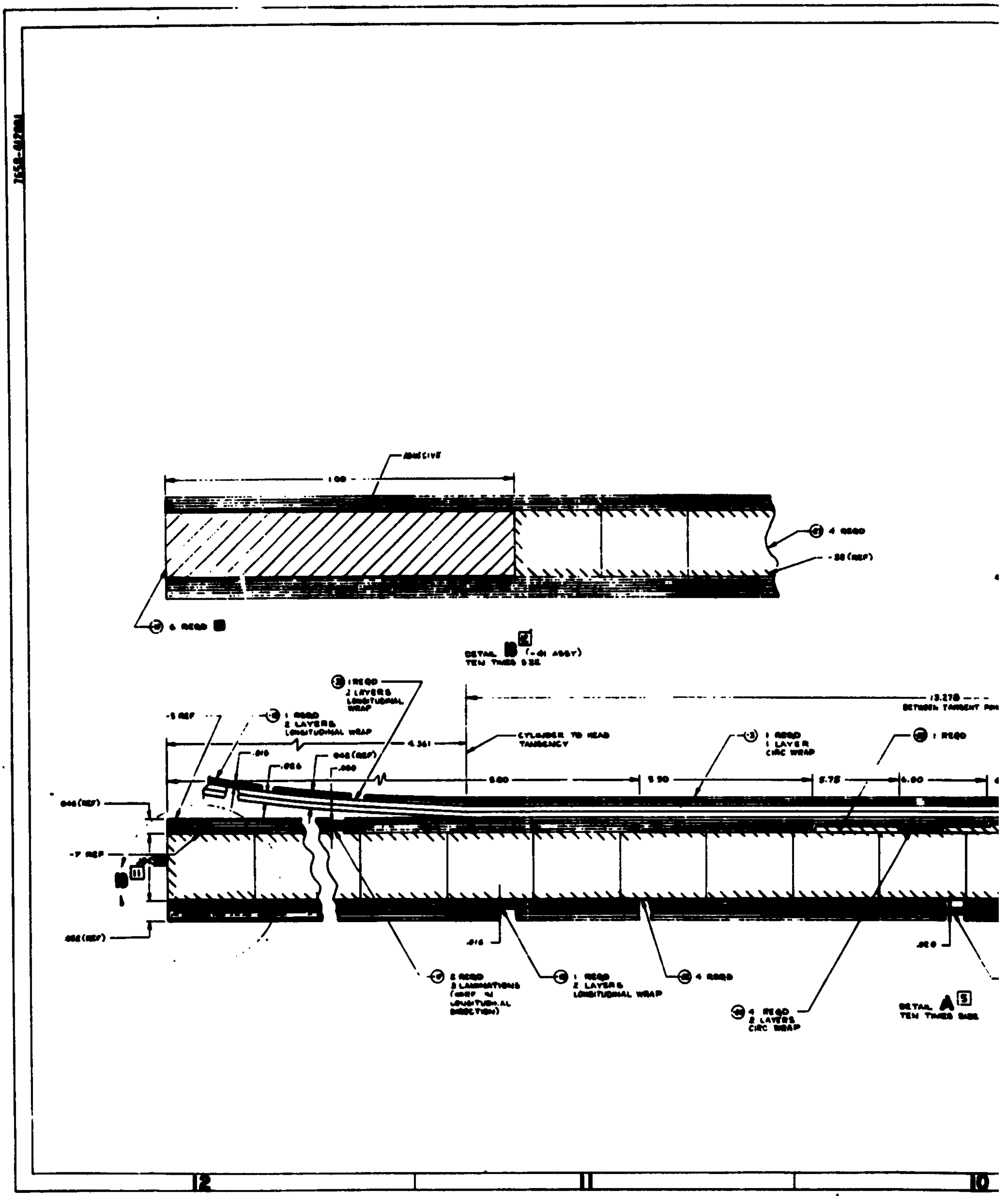
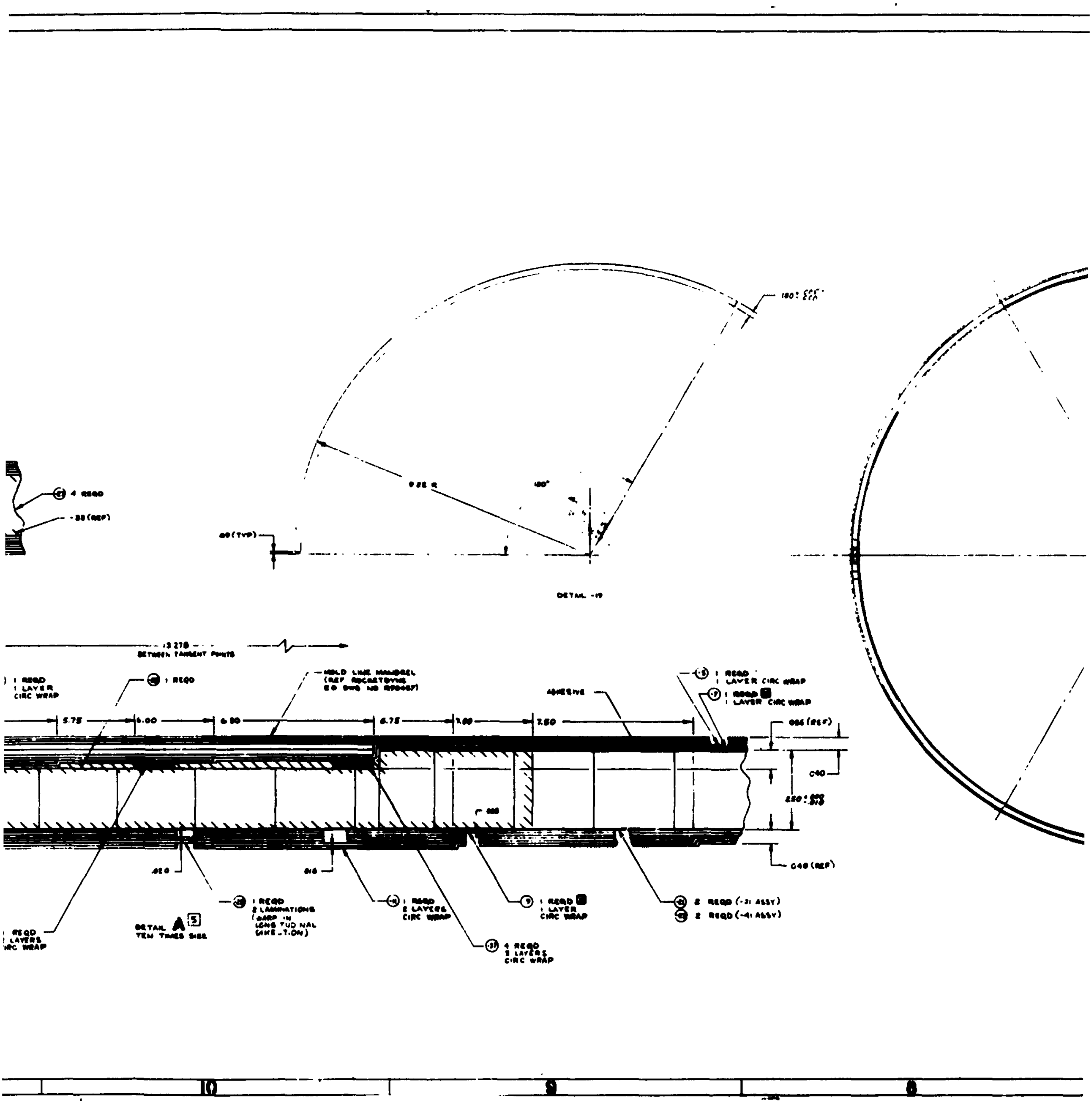
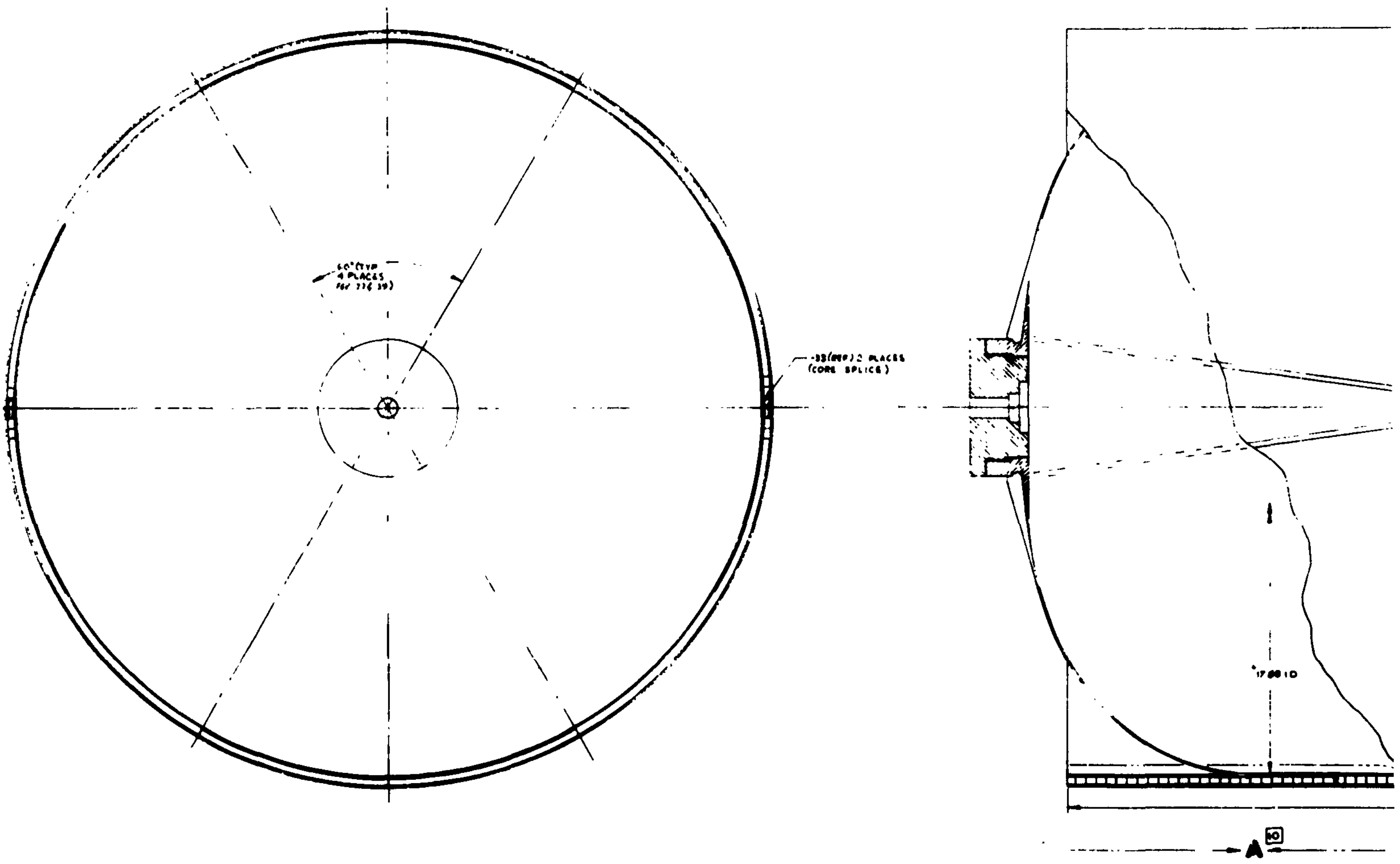

ADHESIVE
4 REQD
DETAIL B (-01 ASSY)
TEN TIMES SIZE
1 REQD
2 LAYERS
LONGITUDINAL WRAP
CYLINDER TO HEAD
TANGENCY
BETWEEN TANGENT
1 LAYER
CIRC WRAP
2 LAYERS
CIRC WRAP
DETAIL A
TEN TIMES SIZE
12
11
10

1



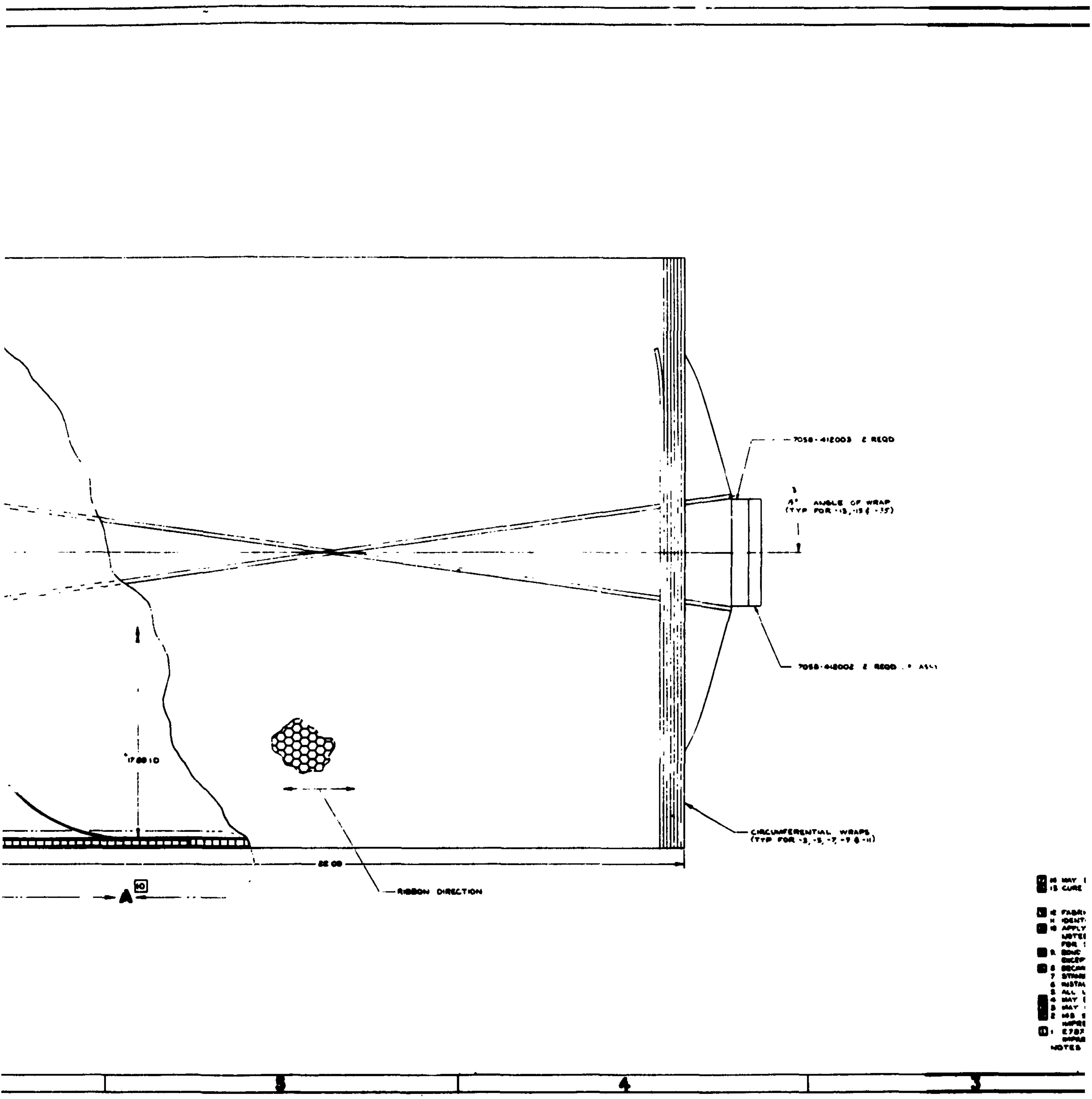
4 REQD
-38 (REF)
.40 (TYP)
9.82 R
180°
DETAIL -19
13.278
BETWEEN TANGENT POINTS
1 REQD
1 LAYER
CIRC WRAP
MOLD LINE MANDREL
ADHESIVE
1 REQD
1 LAYER CIRC WRAP
5.75
6.00
6.90
6.75
7.00
7.50
.056 (REF)
.040 (REF)
DETAIL A
TEN TIMES SIZE
1 REQD
2 LAMINATIONS
1 REQD
2 LAYERS
CIRC WRAP
4 REQD
3 LAYERS
CIRC WRAP
1 REQD
1 LAYER
CIRC WRAP
2 REQD (-31 ASSY)
2 REQD (-41 ASSY)
10
9
8

2



8 7 6

3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5° ANGLE OF WRAP (TYP FOR -13, -15 & -35)
7058-412002 2 REQD
17.89 I.D
CIRCUMFERENTIAL WRAPS (TYP FOR -3, -5, -7, -9 & -11)
RIBBON DIRECTION
A
10
NOTES
5
4
3

4

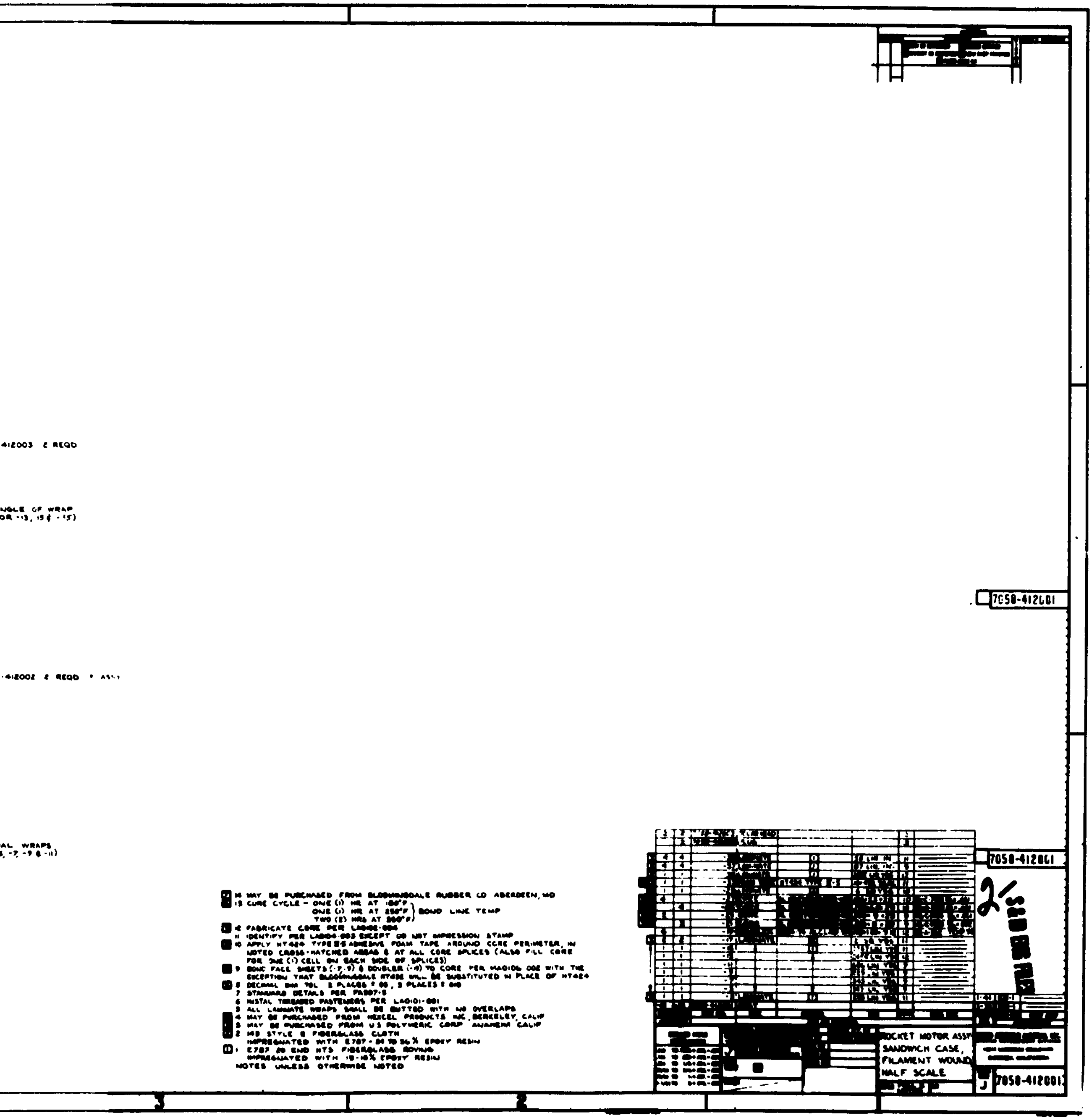
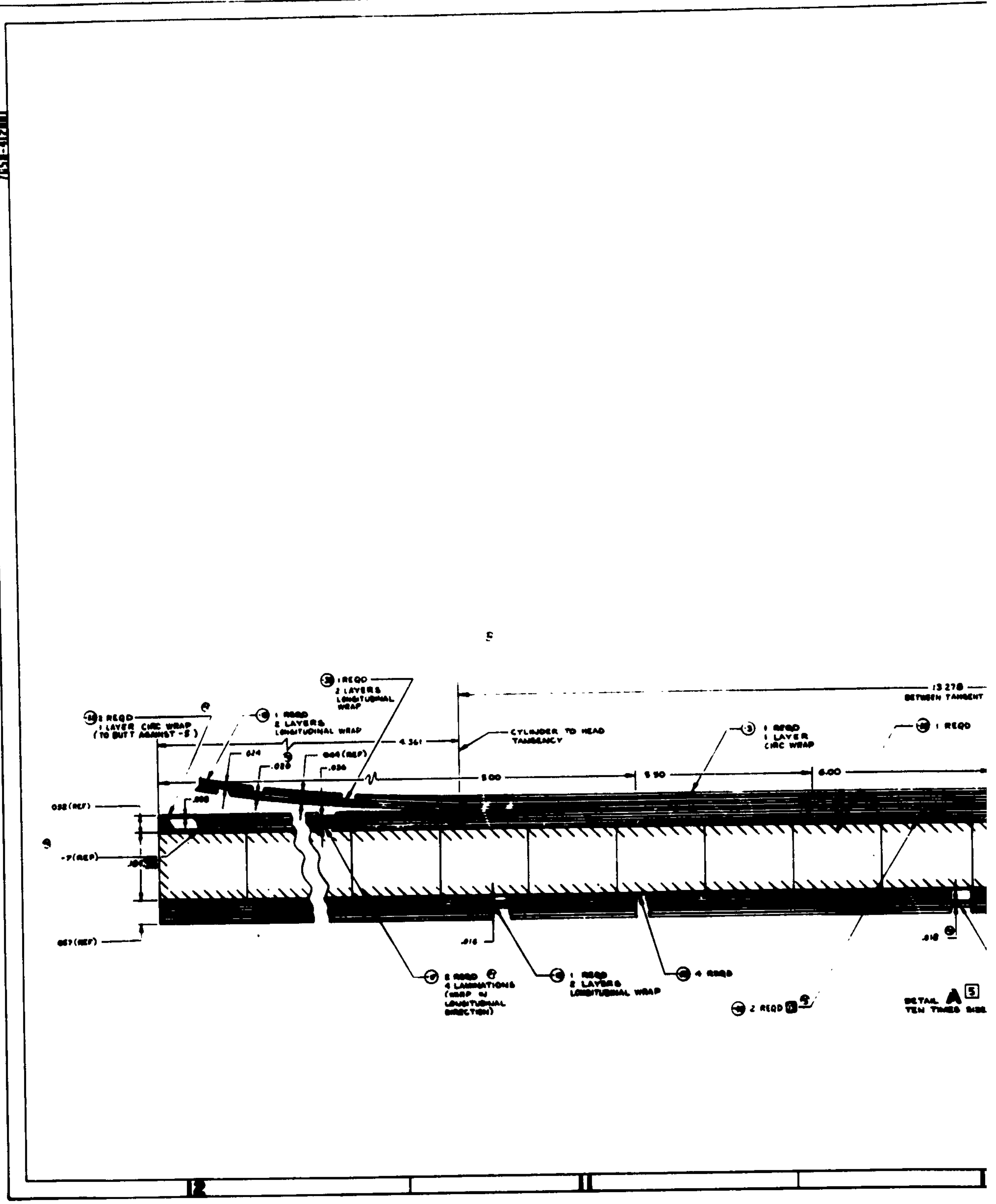
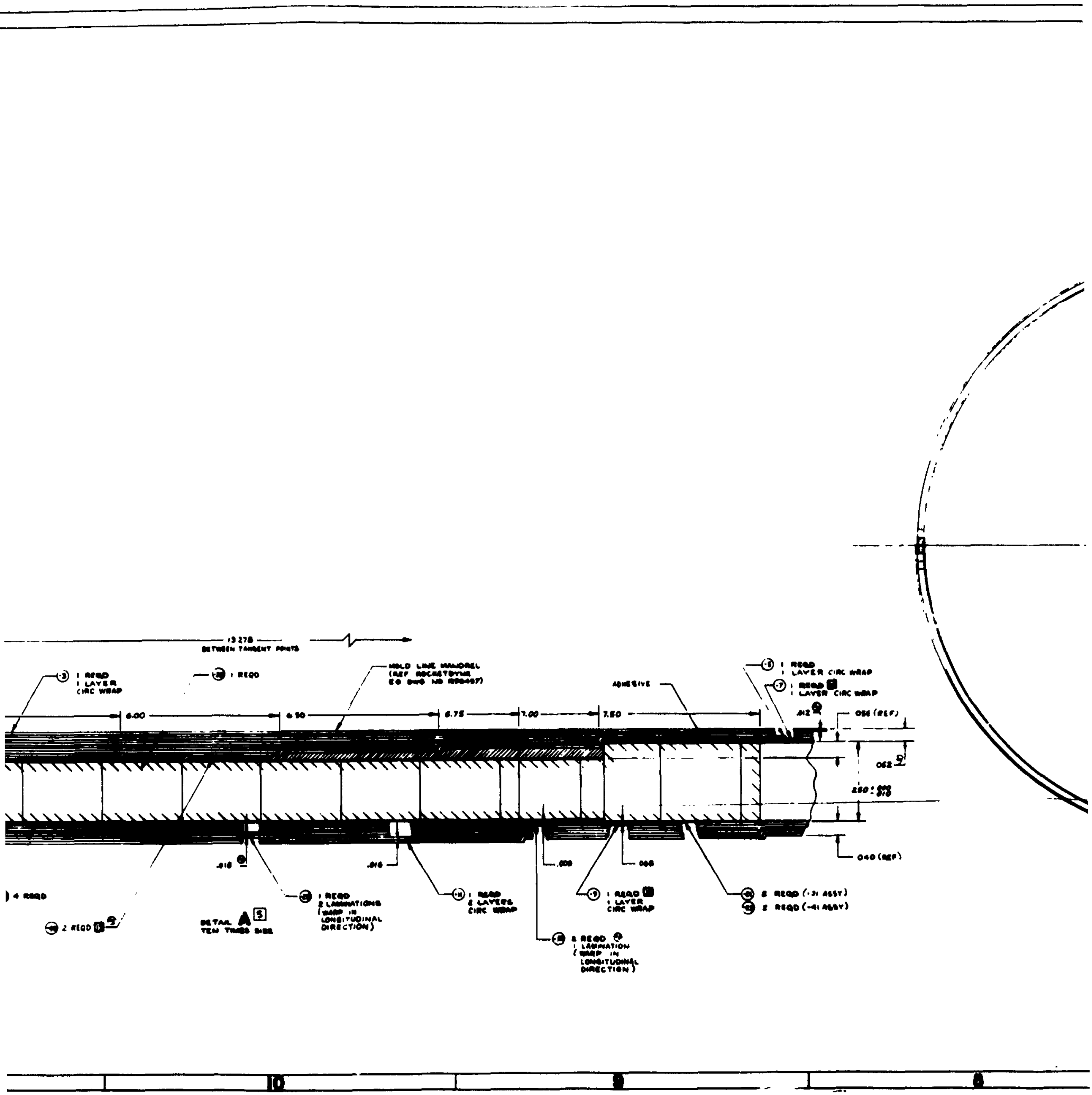


Figure E-1. Drawing of Subscale Cases 1 and 2

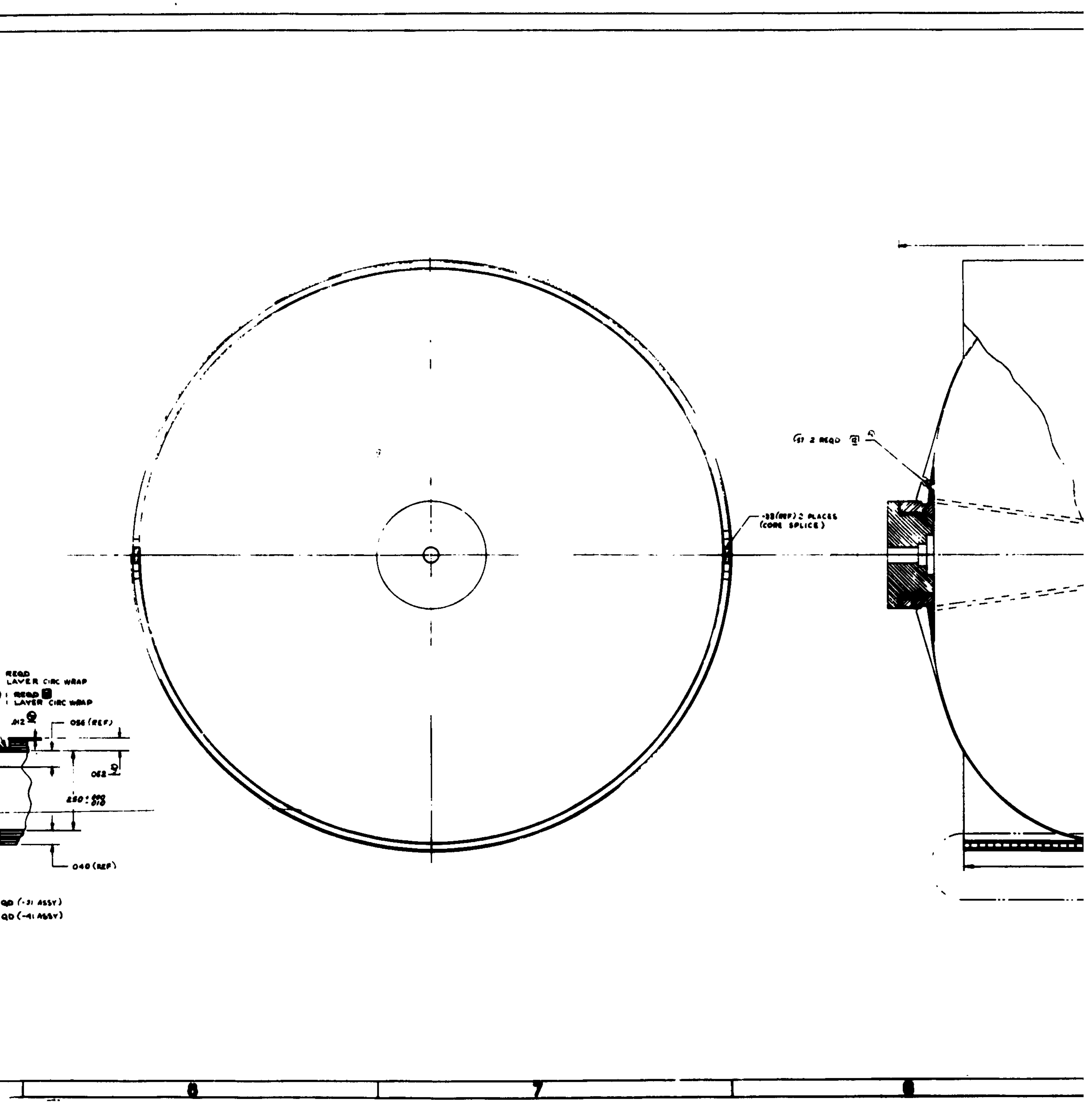

7658-412001
1 REQD
2 LAYERS
LONGITUDINAL WRAP
2 REQD
1 LAYER CIRC WRAP
(TO BUTT AGAINST -5)
1 REQD
2 LAYERS
LONGITUDINAL WRAP
4.361
CYLINDER TO HEAD TANGENCY
13.278
BETWEEN TANGENT
1 REQD
1 LAYER
CIRC WRAP
1 REQD
5.00
5.50
6.00
-7(REF)
.016
2 REQD
4 LAMINATIONS
(WRAP IN LONGITUDINAL DIRECTION)
1 REQD
2 LAYERS
LONGITUDINAL WRAP
4 REQD
2 REQD
DETAIL A
12
11

1



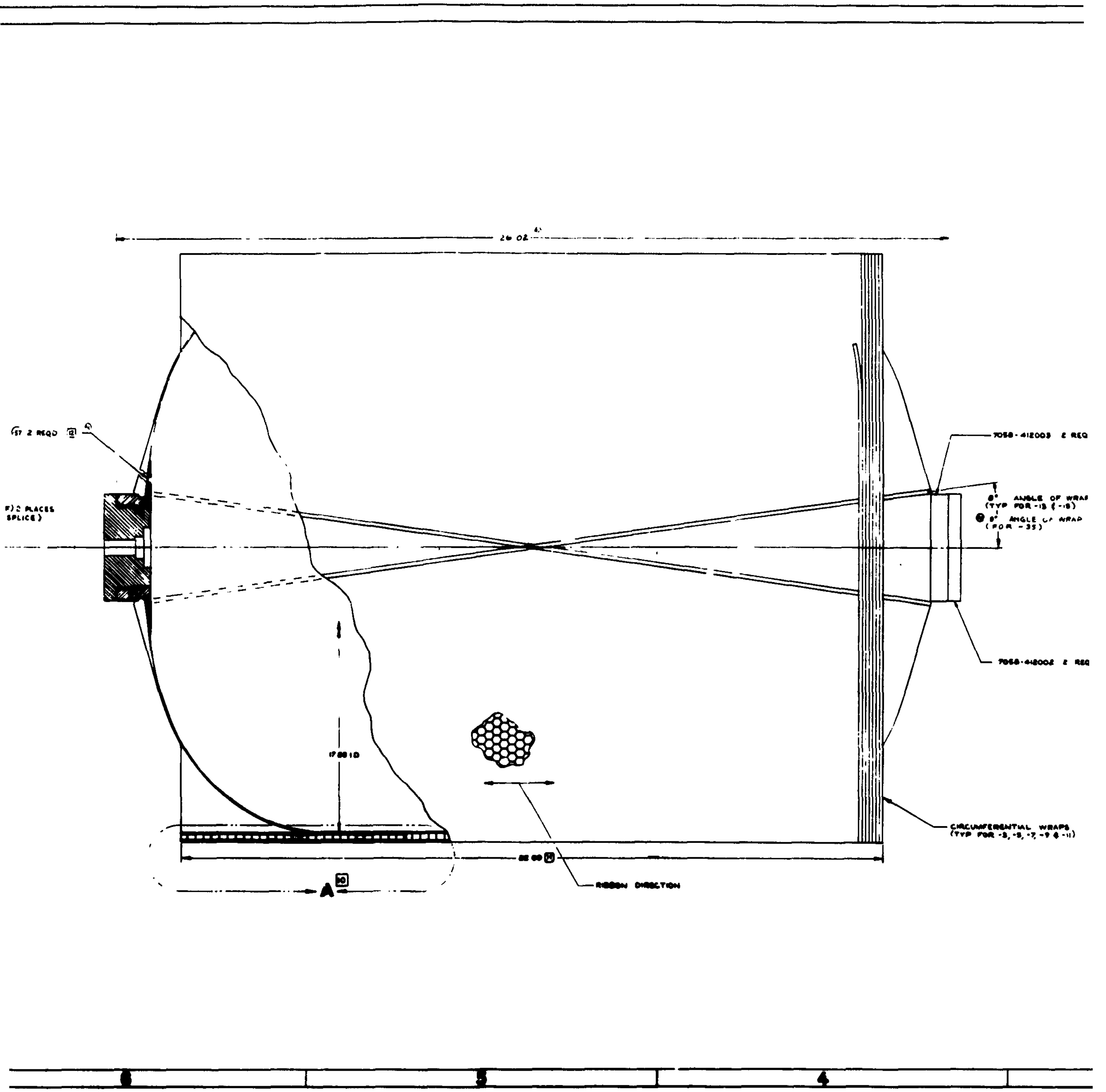
13.278
BETWEEN TANGENT POINTS
1 REQD
1 LAYER
CIRC WRAP
1 REQD
MOLD LINE MANDREL
6.00
6.75
7.00
7.50
ADHESIVE
1 REQD
1 LAYER CIRC WRAP
1 REQD
1 LAYER CIRC WRAP
.056 (REF)
.062
.040 (REF)
.016
.016
4 REQD
2 REQD
DETAIL A 5
TEN TIMES SIZE
1 REQD
2 LAMINATIONS
(WARP IN
LONGITUDINAL
DIRECTION)
1 REQD
2 LAYERS
CIRC WRAP
1 REQD
1 LAYER
CIRC WRAP
2 REQD (-31 ASSY)
2 REQD (-41 ASSY)
1 LAMINATION
(WARP IN
LONGITUDINAL
DIRECTION)
10
9
8

2

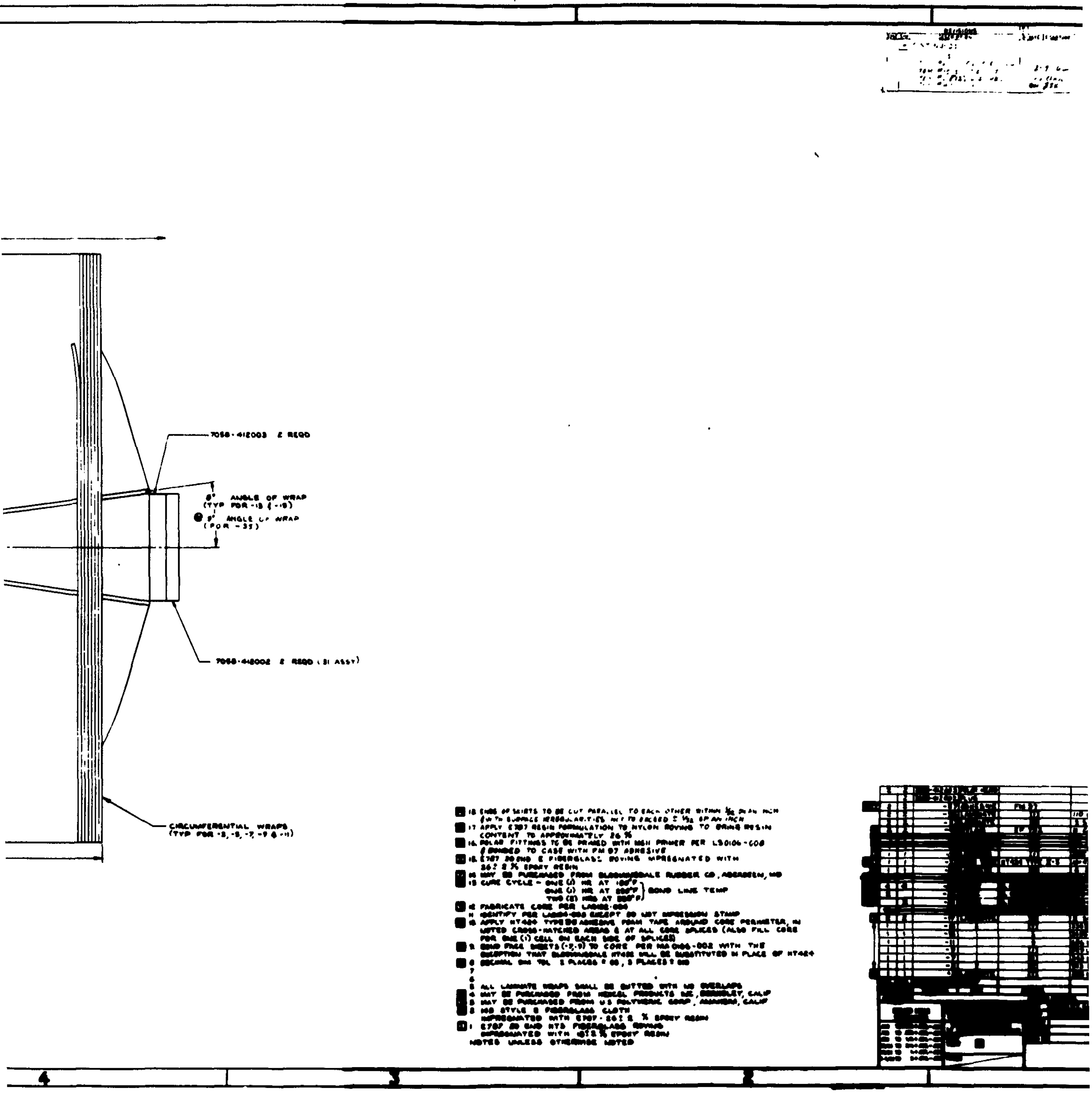


REQD
LAYER CIRC WRAP
1 REQD
1 LAYER CIRC WRAP
.012
.056 (REF)
.062
.250
.040 (REF)
QD (-31 ASSY)
QD (-41 ASSY)
-51 2 REQD
-33(REF) 2 PLACES
(CORE SPLICE)
6
7
8

3


26.02
7058-412003 2 REQ
ANGLE OF WRAP
(TYP FOR -13 & -15)
ANGLE OF WRAP
(FOR -35)
7058-412002 2 REQ
CIRCUMFERENTIAL WRAPS
(TYP FOR -3, -5, -7, -9 & -11)
RIBBON DIRECTION
2 REQD
2 PLACES
SPLICE)
A
4

4



5

Figure E-2. Drawing of Subscale Case

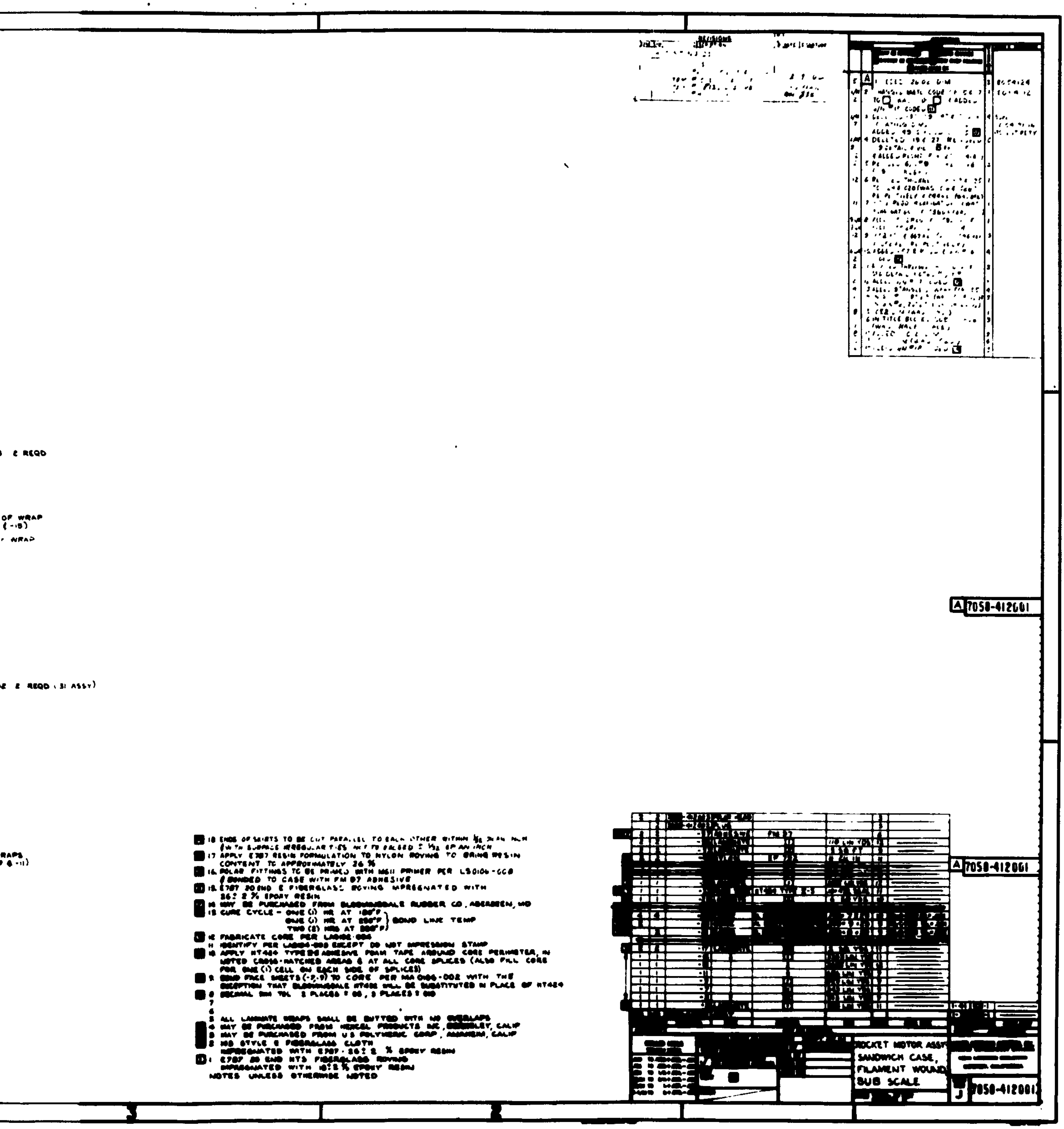
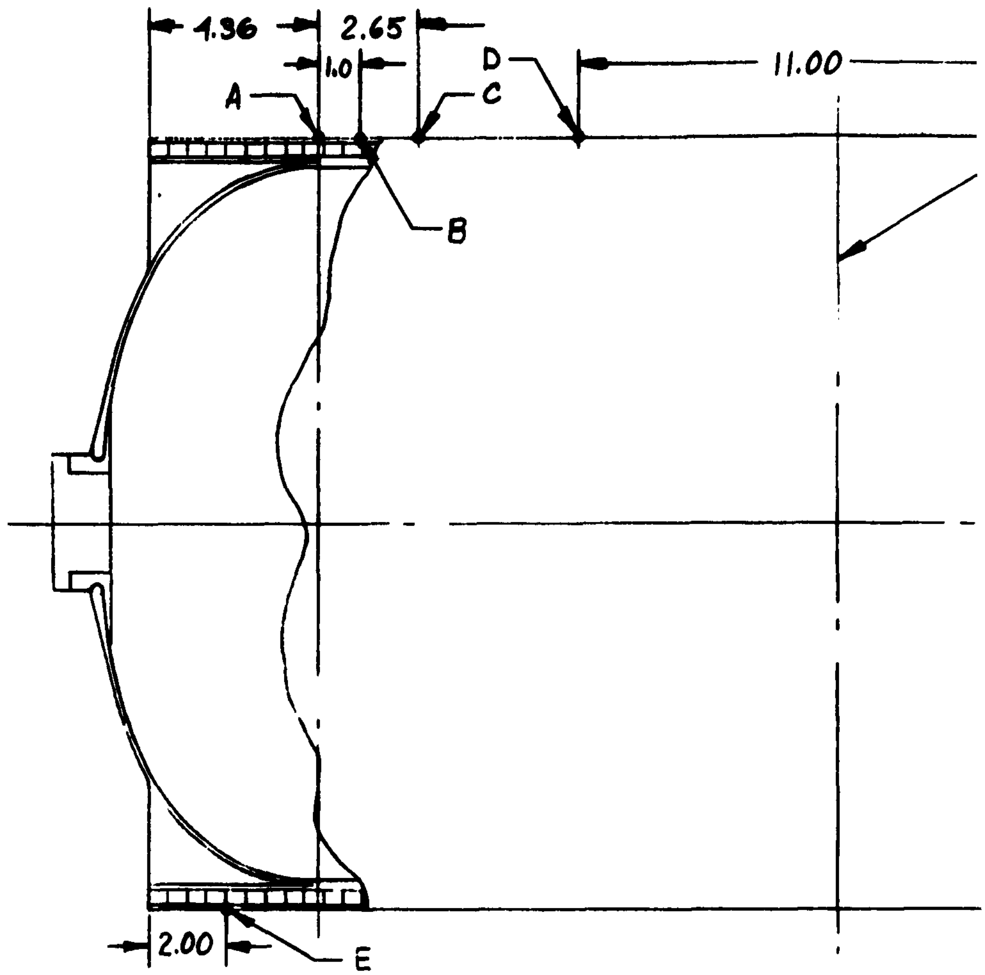


Figure E-2. Drawing of Subscale Cases 5 and 6

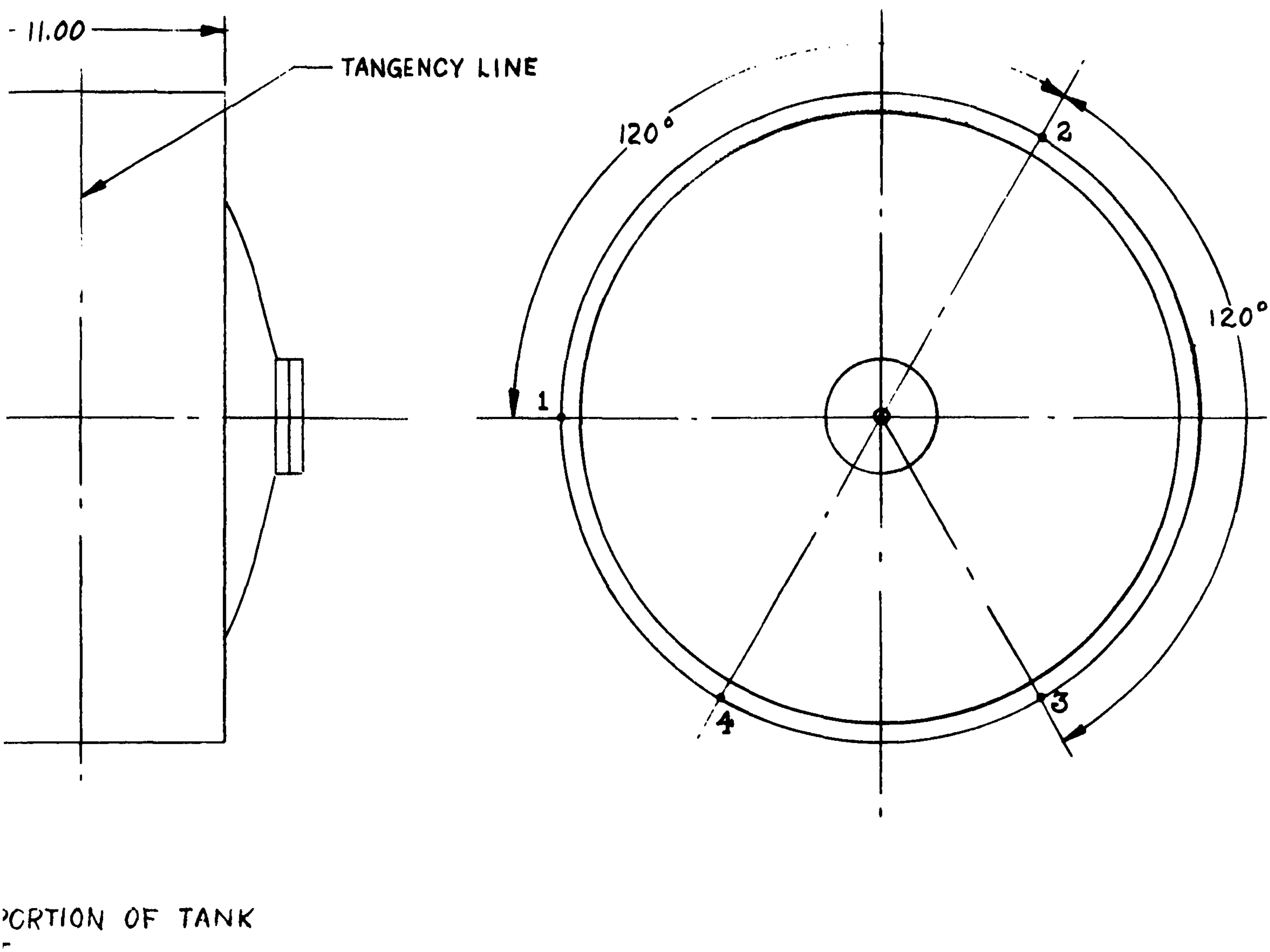
6



A. TANGENCY POINT OF CYLINDER AND DOME
B. POINT 5.36 INCHES FROM END OF SKIRT
C. POINT 7.01 INCHES FROM END OF SKIRT
D. GAGE LEVEL AT CENTER SPAN OF CYLINDRICAL PORTION OF TA
E. POINT 2.00 INCHES FROM END OF SKIRT

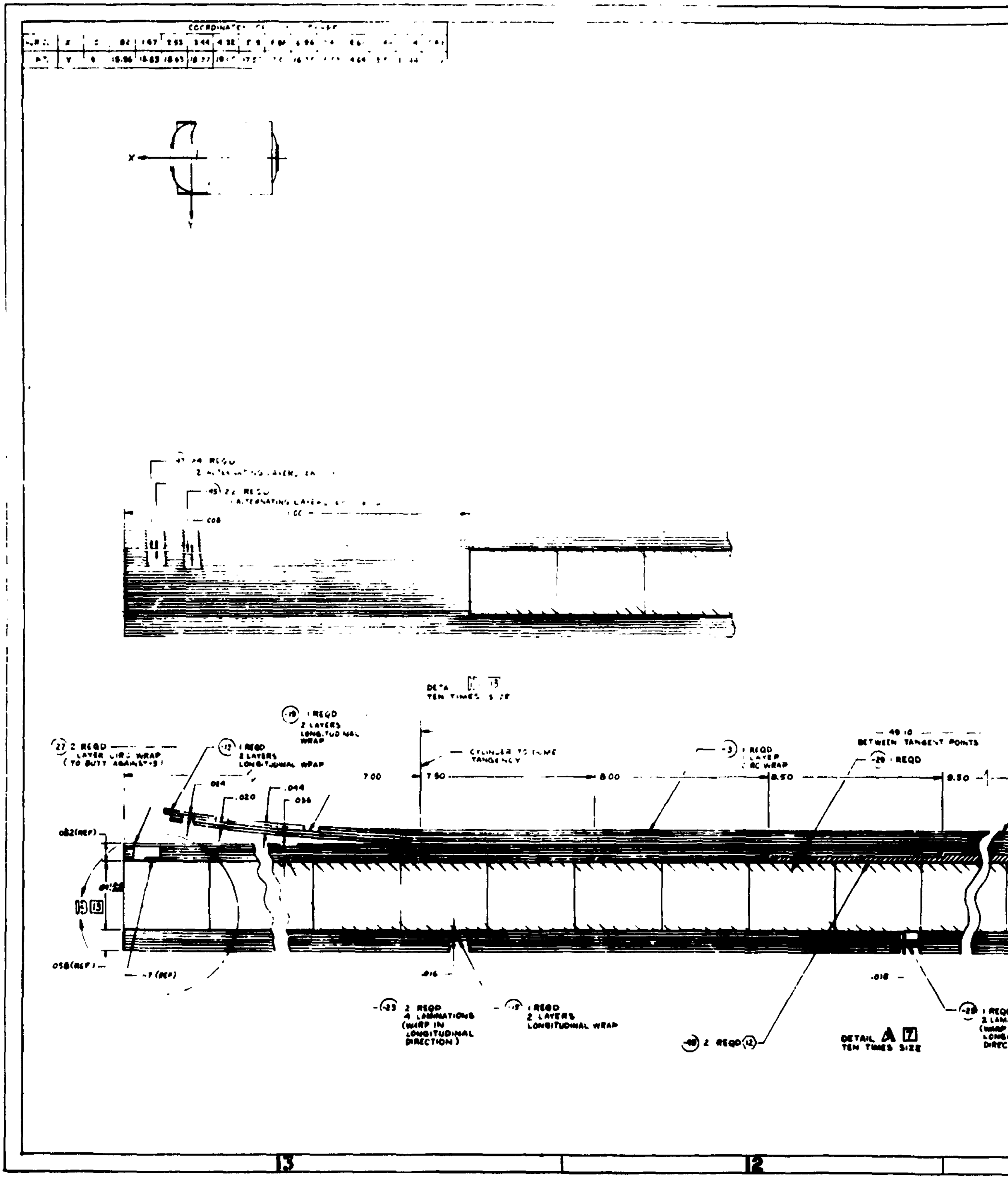
TENSION LOADED (PRESSURIZED) TANKS

TANKS #4 & #6: CIRCUMFERENTIAL GAGES AT A2, A4 AND
D2 & D3.
VERTICAL GAGES AT B2, B4, C2, C4, D1, D2 &



AT A2, A4 AND D1, C2, C4, D1, D2 & D3	COMPRESSION LOADED TANKS TANKS #2, #3, & #5: CIRCUMFERENTIAL AND VERTICAL GAGES AT D1, D2 & D3 VERTICAL GAGES ONLY AT B2, B4, C2, C4, E2 & E4

Figure E-3. Strain Gage Locations for Subscale Cases

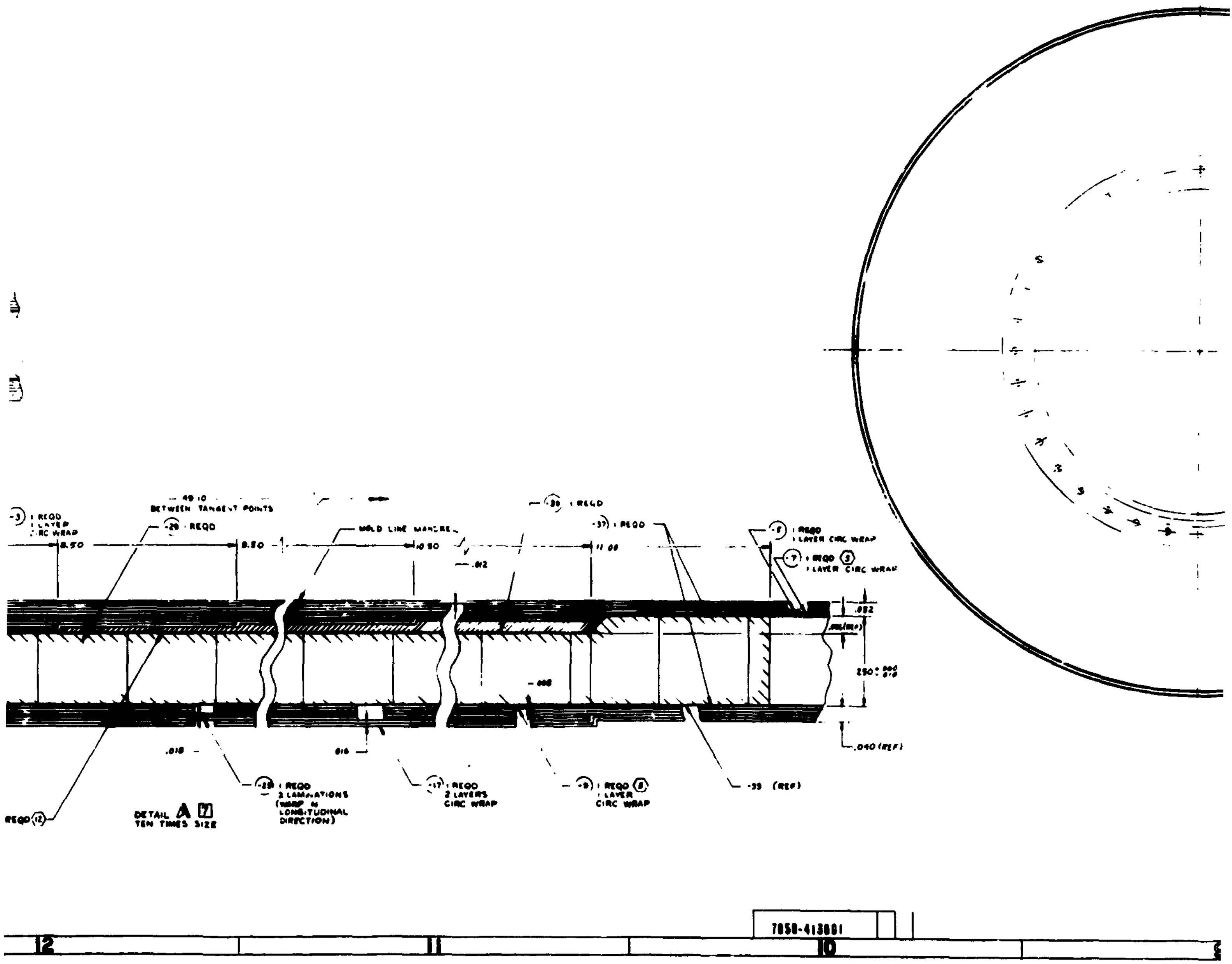


COORDINATES
X
Y
2 REQD
LAYER GIRTH WRAP
(TO BUTT AGAINST -3)
1 REQD
2 LAYERS
LONGITUDINAL WRAP
CYLINDER TO DOME TANGENCY
7.00
7.50
8.00
8.50
49.10
BETWEEN TANGENT POINTS
1 REQD
1 LAYER
.082(REF)
.058(REF)
.016
.018
2 REQD
4 LAMINATIONS
(WARP IN LONGITUDINAL DIRECTION)
2 REQD
DETAIL A
TEN TIMES SIZE

13

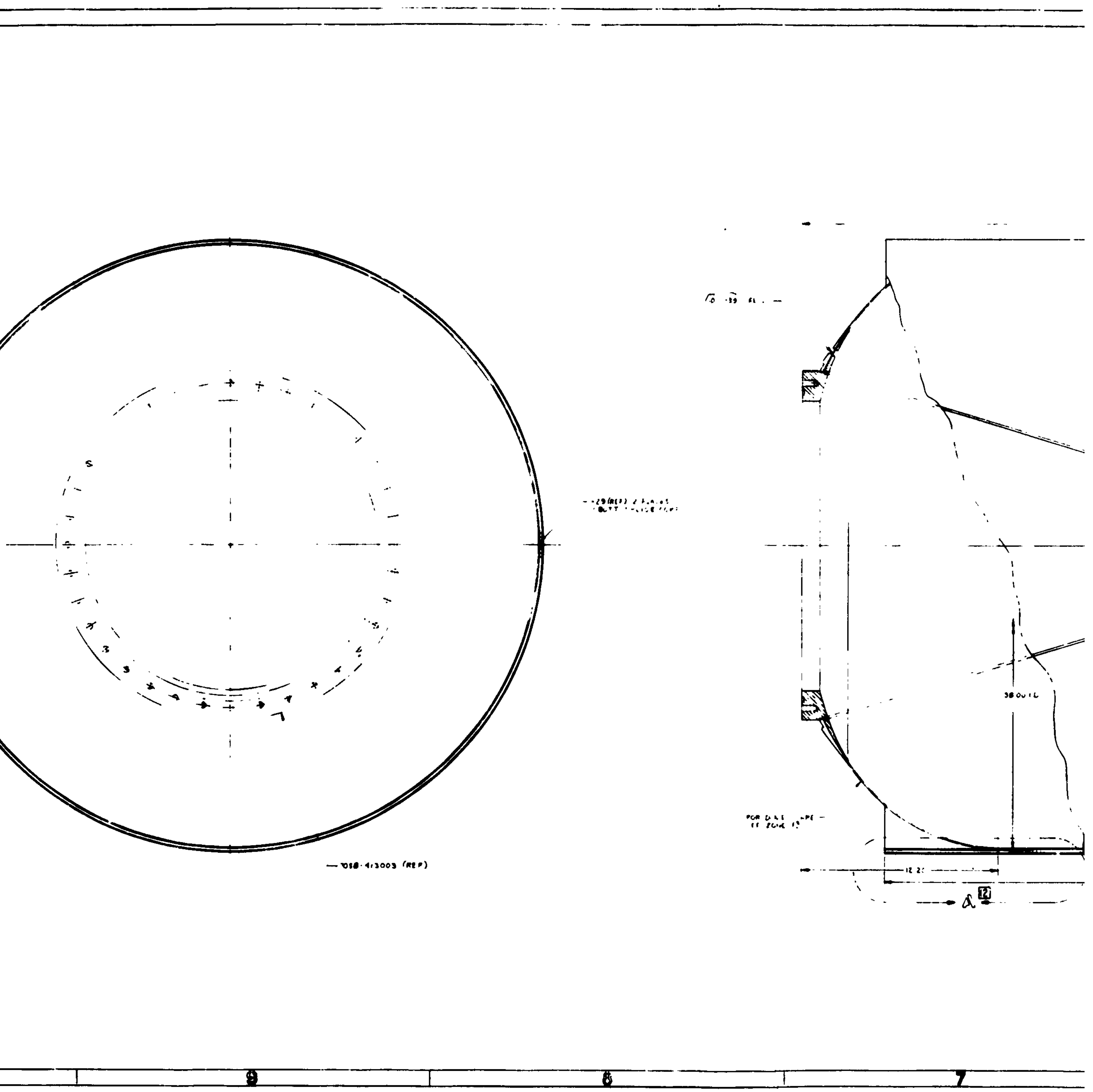
12

1

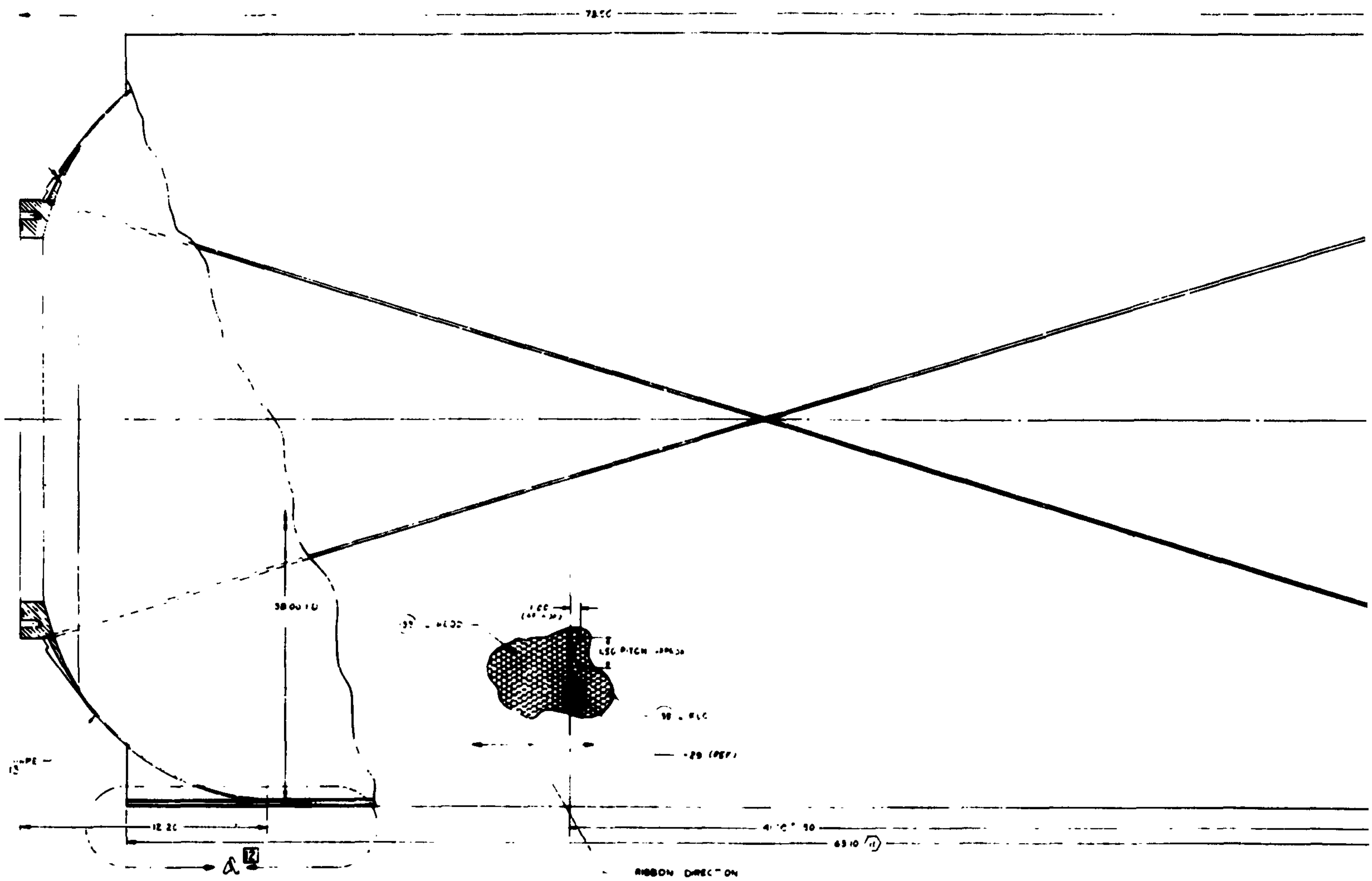


49.10
BETWEEN TANGENT POINTS
-3 1 REQD 1 LAYER CIRC WRAP
-29 1 REQD
MOLD LINE MANDREL
-30 1 REQD
-37 1 REQD
-5 1 REQD 1 LAYER CIRC WRAP
-7 1 REQD 5 1 LAYER CIRC WRAP
8.50
9.50
10.50
11.00
.012
.032
.250
.040 (REF)
.018
.016
-25 1 REQD 2 LAMINATIONS (WARP IN LONGITUDINAL DIRECTION)
-17 1 REQD 2 LAYERS CIRC WRAP
-9 1 REQD 6 1 LAYER CIRC WRAP
-39 (REF)
REQD 12
DETAIL A 7
TEN TIMES SIZE
7850-413001
12
11
10

2



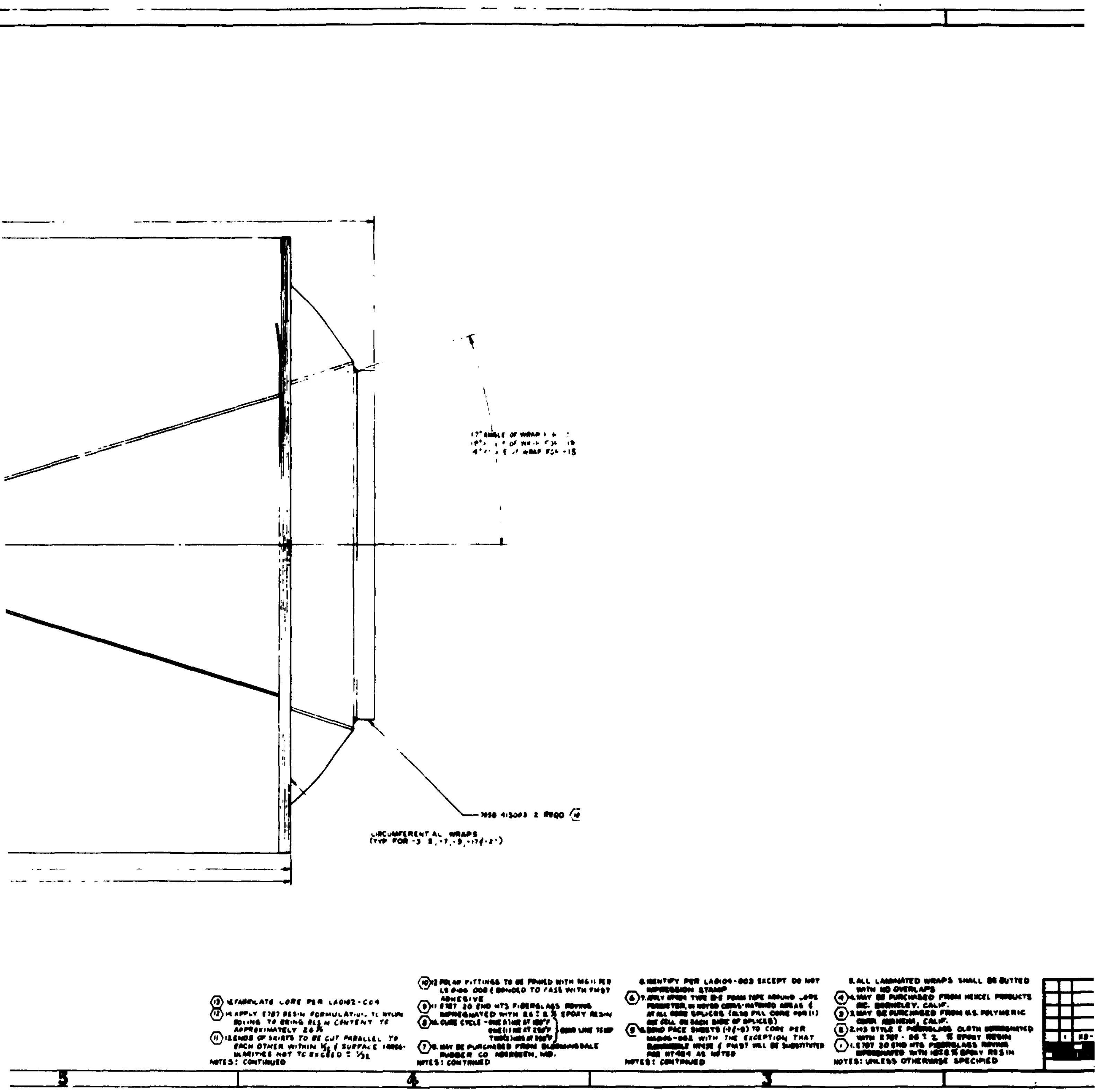
3



7058-413C01

7 6 5

4



CIRCUMFERENTIAL WRAPS (TYP FOR -3 5, -7, -9, -17 (-2-)
13. FABRICATE CORE PER LA0102-C04
12. APPLY E787 RESIN FORMULATION TO NYLON ROVING TO BRING RESIN CONTENT TO APPROXIMATELY 26%
11. ENDS OF SKIRTS TO BE CUT PARALLEL TO EACH OTHER WITHIN 1/32 & SURFACE IRREGULARITIES NOT TO EXCEED ± 1/32
NOTES: CONTINUED
10. POLAR FITTINGS TO BE PRIMED WITH M611 PER LS 0100-008 & BONDED TO CASE WITH FM97 ADHESIVE
9. E787 20 END HTS FIBERGLASS ROVING IMPREGNATED WITH 26 ± 2% EPOXY RESIN
8. CURE CYCLE - BOND LINE TEMP
7. MAY BE PURCHASED FROM RUBBER CO ABERDEEN, MD.
NOTES: CONTINUED
6. IDENTIFY PER LA0104-003 EXCEPT DO NOT IMPRESSION STAMP
5. BOND FACE SHEETS (-7 & -8) TO CORE PER LA0106-002 WITH THE EXCEPTION THAT WILL BE SUBSTITUTED AS NOTED
NOTES: CONTINUED
5. ALL LAMINATED WRAPS SHALL BE BUTTED WITH NO OVERLAPS
4. MAY BE PURCHASED FROM HEXCEL PRODUCTS INC. BERKELEY, CALIF.
3. MAY BE PURCHASED FROM U.S. POLYMERIC CORP. ANAHEIM, CALIF.
2. 143 STYLE E FIBERGLASS CLOTH IMPREGNATED WITH E787 - 26 ± 2 % EPOXY RESIN
1. E787 20 END HTS FIBERGLASS ROVING IMPREGNATED WITH % EPOXY RESIN
NOTES: UNLESS OTHERWISE SPECIFIED
5
4
3

5

Figure

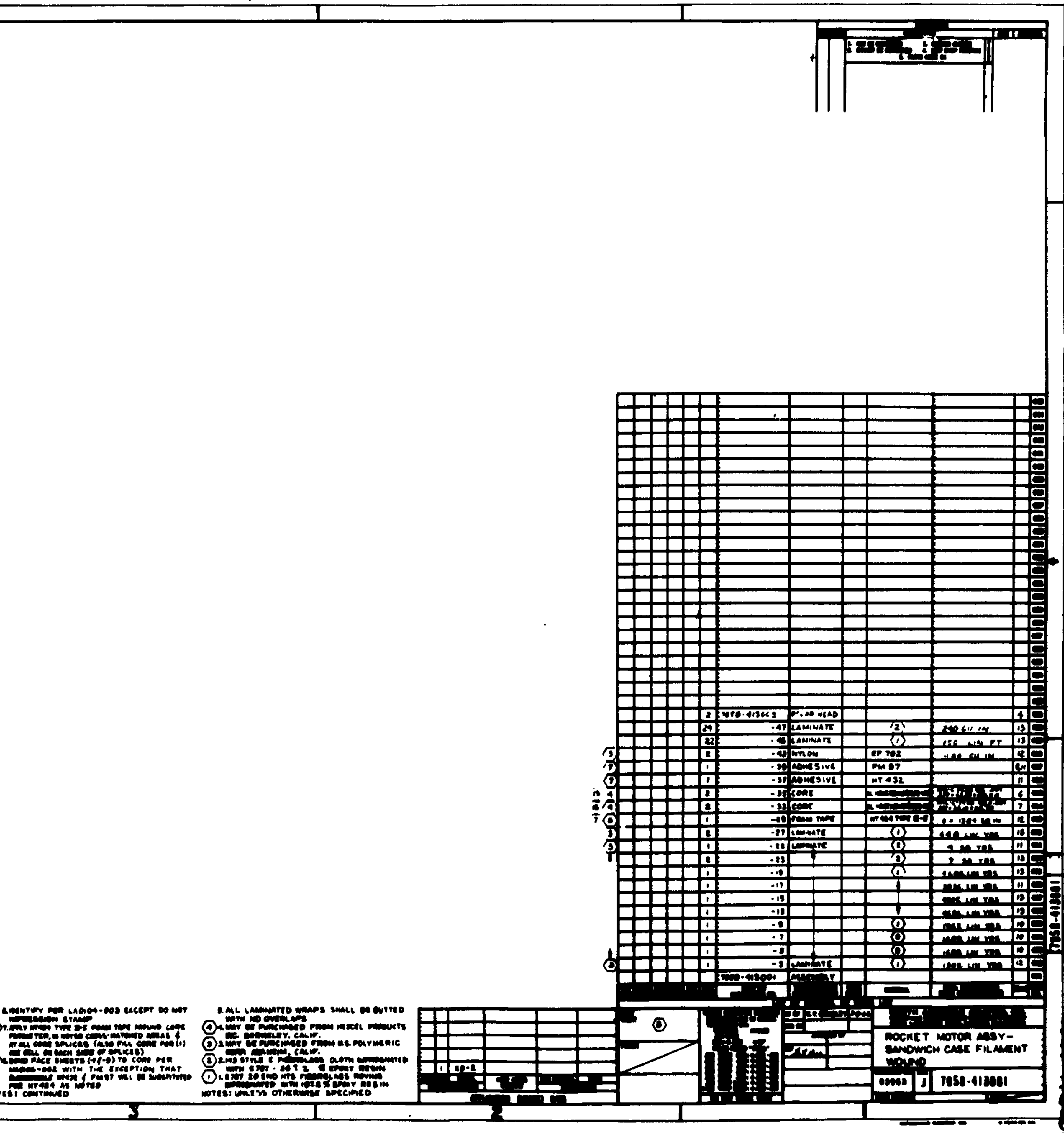
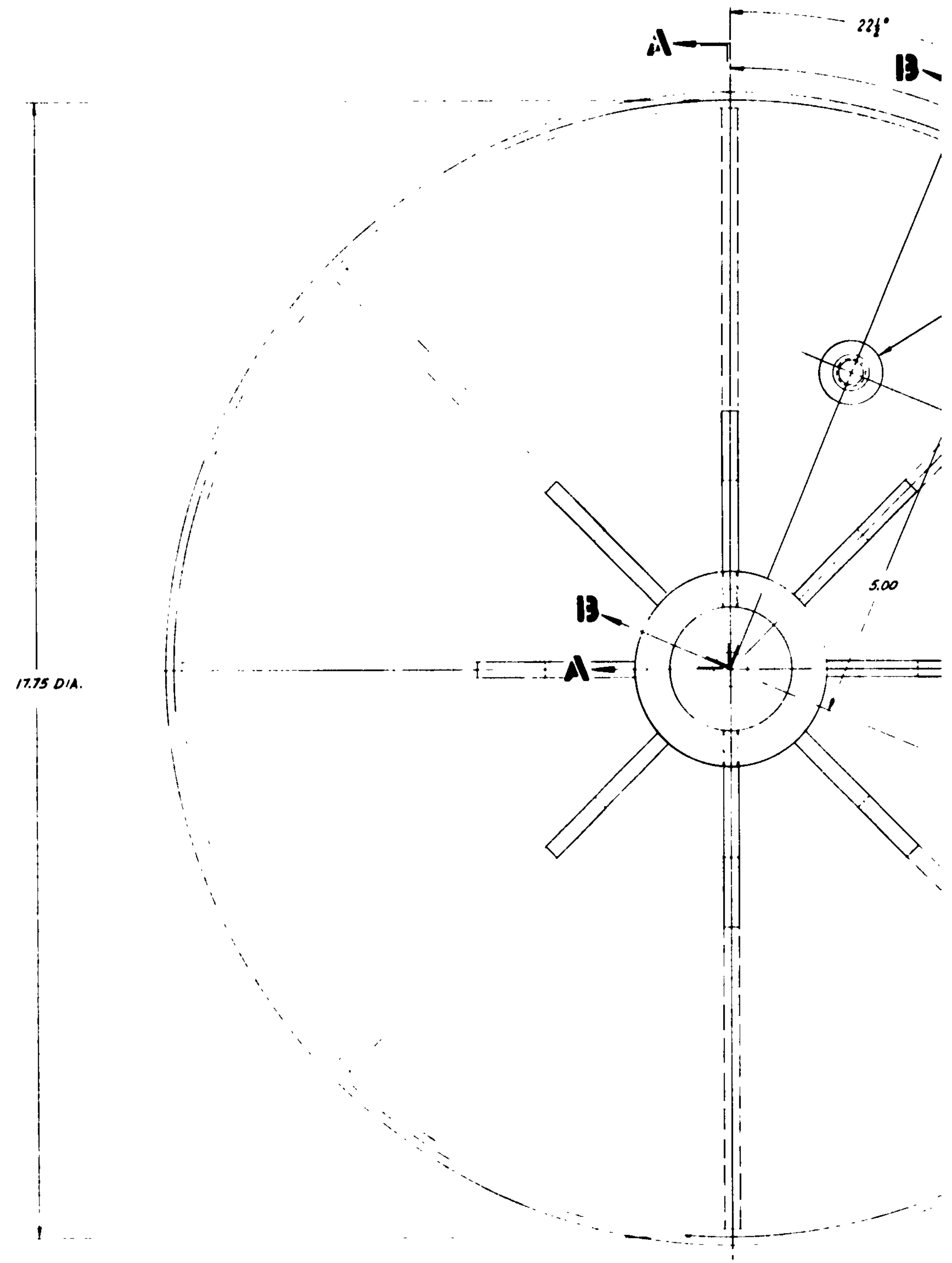
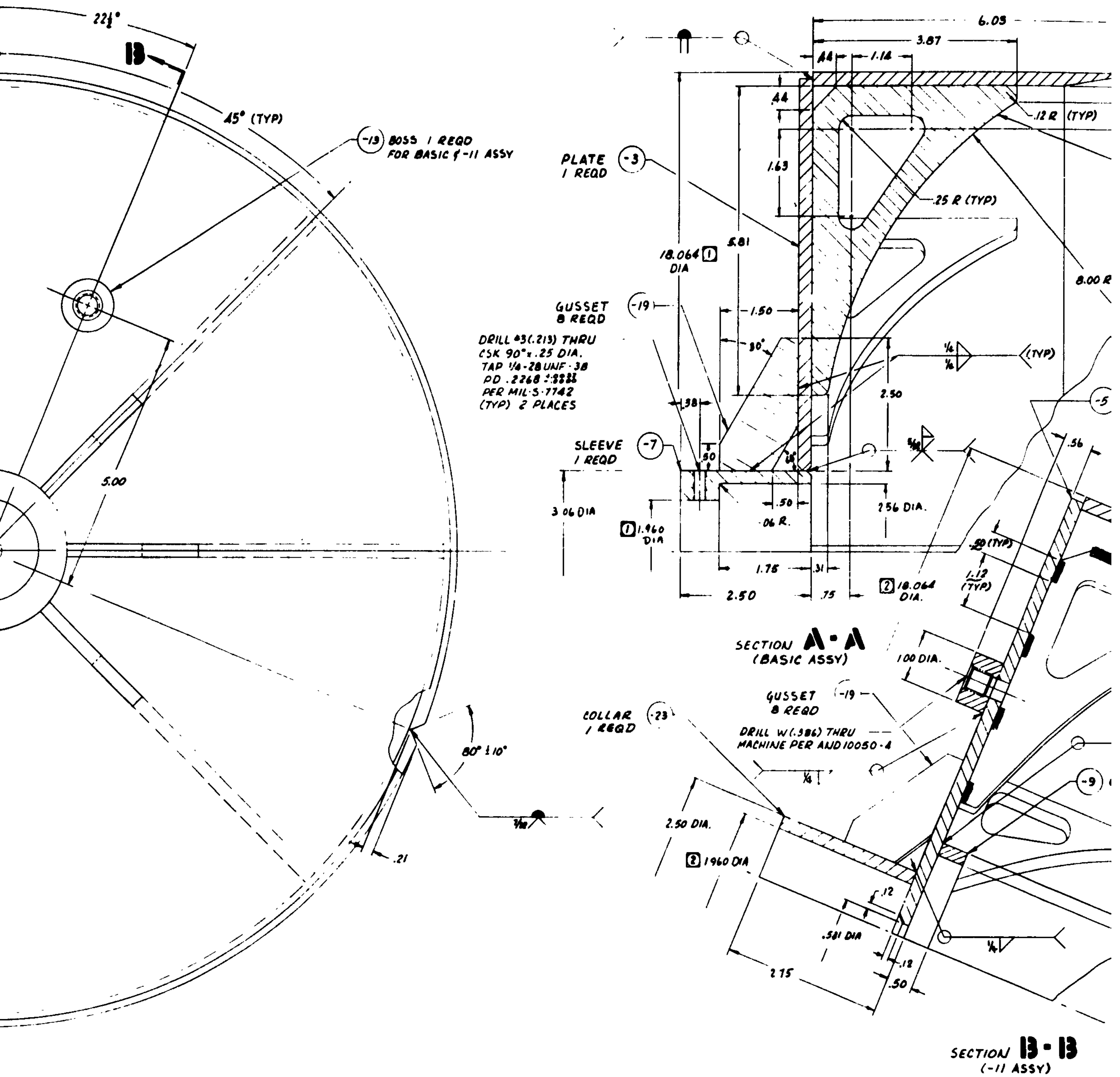


Figure E-4. Drawing of Full-Scale Motor Cases



A
22½°
B
17.75 DIA.
5.00
B
A


22½°
45° (TYP)
(-13) BOSS 1 REQD FOR BASIC ⊄ -11 ASSY
5.00
80° ± 10°
.21
PLATE (-3) 1 REQD
18.064 1 DIA
5.81
GUSSET (-19) 8 REQD
DRILL #3(.213) THRU
CSK 90° x .25 DIA.
TAP 1/4-28 UNF-3B
PD .2268
PER MIL-S-7742
(TYP) 2 PLACES
SLEEVE (-7) 1 REQD
3.06 DIA
1 1.960 DIA
6.03
3.87
.44
1.14
.12 R (TYP)
1.63
.25 R (TYP)
8.00 R
1.50
30°
(TYP)
2.50
.38
.50
.06 R.
2.56 DIA.
1.75
.31
2.50
.75
2 18.064 DIA.
SECTION A-A
(BASIC ASSY)
.56
.50 (TYP)
1.12 (TYP)
1.00 DIA.
GUSSET (-19) 8 REQD
DRILL W(.386) THRU
MACHINE PER AND10050-4
COLLAR (-23) 1 REQD
2.50 DIA.
2 1.960 DIA
.12
.581 DIA
2.15
.12
.50
(-9)
SECTION B-B
(-11 ASSY)

2

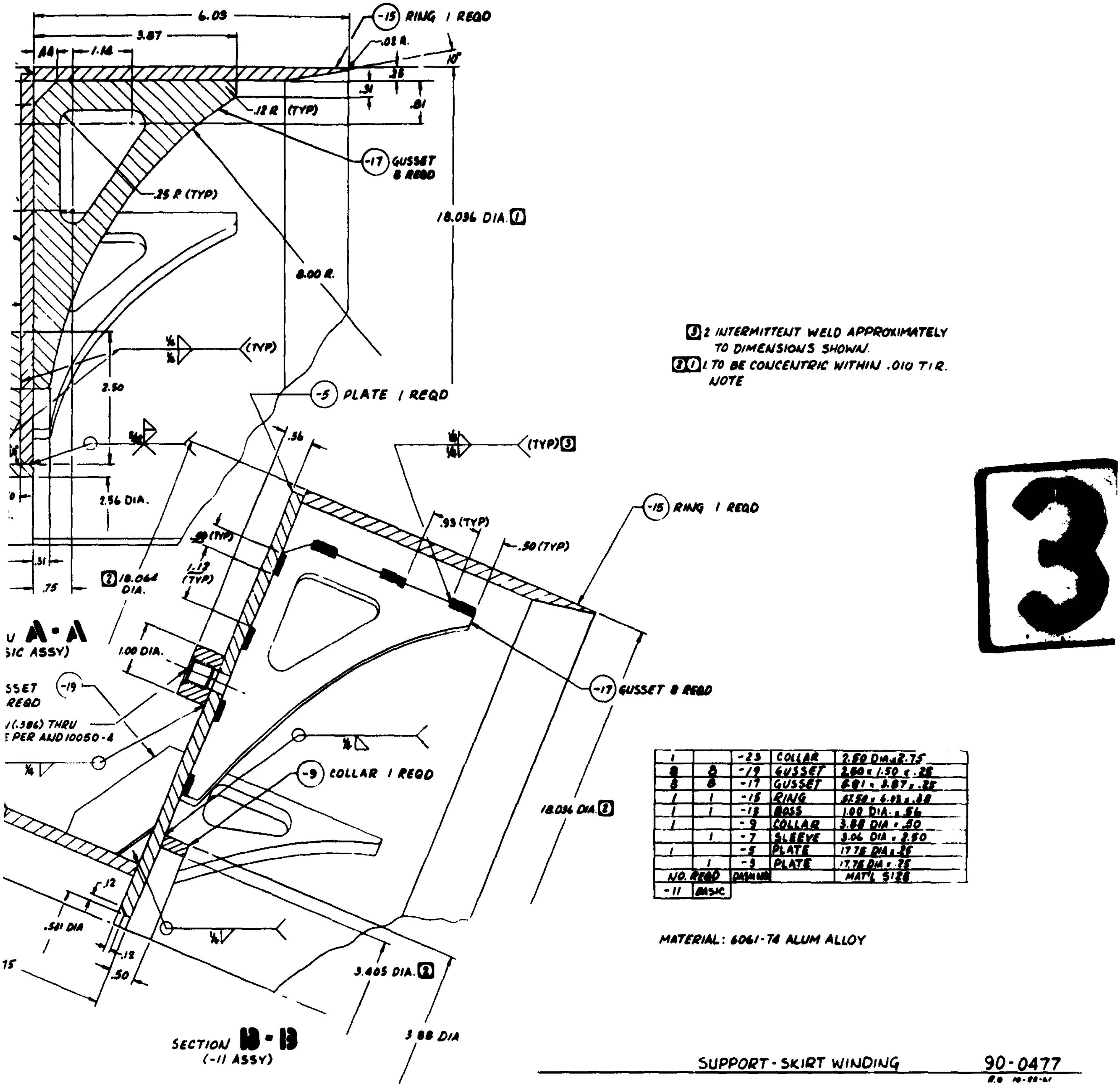


Figure E-5. Drawing of End Skirt Fixture for Subscale Case

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